MECHANICAL DRAWING

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MECHANICAL DRAWING

BY

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PREFACE

This book is the result of years of experience in the drafting room and behind the desk. The methods pursued therein combine the best practice in this country and abroad, based on the writer's intimate knowledge of German engineering education.

While the book is primarily written for Engineering Colleges, with certain omissions, it furnishes an excellent textbook for High Schools, Trade Schools, Evening Drawing Classes and Home Study.

The course to be covered by the Cooper Union Schools is with slight modifications roughly as follows:

Day School of Technical Science:

1. Year of drawing: Chap. I. to V. incl.
2. Year of drawing: Chap. VI. (in conjunction with Textbooks on Elementary Design.)

Evening Schools of General Science and Electrical Engineering:

1. Year of drawing: Chap. I. to III. B. incl.
2. Year of drawing: Chap. III. C. to VI. A. incl.

The Chapters IV. and V. are curtailed to some extent in the Evening Schools.

The merit claimed for this work is the systematically-arranged selection of lessons in form of drawing plates which, for the greater part, are reproductions as to size of paper and proper arrangement of the problems of the finished drawing.

The problems, of course, are unfinished on the printed plate, and their specifications, given in the text, may vastly vary with every instructor, but the underlying principles of construction in each case are expressed "graphically"; that is, in the language of the Draftsman. And thereby the author has tried to avoid the great evil, of which most other books on Mechanical Drawing suffer, namely: *big books with a whole lot of reading matter (which is hardly ever read by the student) and very little (usually poor) drawing.*

The explanations in this book are simple and direct, stripped of all needless words, teaching the student to develop his own thinking power.

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MECHANICAL DRAWING.

CHAPTER I.

INTRODUCTORY REMARKS.

A—Drawing Tools and Their Use.

"A good draftsman must have good instruments" goes without saying. That is, the best instruments obtainable are just good enough. They need, however, not be elaborate, and, perhaps, for young beginners, may be of a cheaper quality, until the student has found out whether he is gifted for the art of drafting.

The following is a list of all that is needed to begin drawing:

1 set of instruments.
1 drawing board.
1 tee-square.
2 triangles, 30° and 45°.
1 scale (for different scales use triangular boxwood scale).
1 bottle of black drawing ink.
2 pencils, 3H and 6H.
4 thumb tacks.
1 ink and pencil eraser.
1 penholder with pen.

Later on he may need one *French curve* for drawing such curves that cannot be drawn with the compass, one *protractor*, to measure various angles, one pair of *calipers*, to take measurements from models when sketching.

Instruments.—They should at the least contain the following 4 parts:

1 *compass*, for drawing circles and arcs with pencil or ink.

1 *pair of dividers*, for dividing lines into certain required parts or transferring dimensions from one part of the drawing to another.

1 *ruling pen* for drawing straight lines.

1 *bow pen* for drawing very small circles and arcs.

Tee-Square and Triangles.—By means of the Tee-square, which rests with the head against the *left* edge of the board, all *horizontal* lines are drawn along the *upper* edge of the blade. By means of the Triangles all *vertical* lines are drawn (draftsman turned to left and drawing the lines *upward*). By combining the triangles as shown in Fig. 1, various other angles may be drawn. (Draftsman should try to obtain such angles by different positions of triangles.)

B—Drafting Room and Shop Practice.

Drafting Room.—The personnel of a modern drafting room usually consists of a chief draftsman and a number of designers or draftsmen having an engineering knowledge. Each designer has a number of assistants, to make tracings and detail drawings. There will also be one or more persons to make blue prints, take care of the drawings and probably act as time keeper.

Working drawings are generally made on brown detail paper in pencil, traced on tracing cloth and then blue printed. The process of tracing is as follows: Place the tracing cloth over the pencil-drawing, either side of the tracing cloth being used for inking in. Then rub powdered chalk with a soft rag on it, in order to make the cloth take the ink well. The powder must be rubbed off gently. Before attempting to draw any lines on the tracing cloth, try the pen on the edge of the cloth outside the boundary lines on which the tracing is to be cut, until the pen works freely and produces lines of the required thickness.

Machine Shop.—The blue print is first sent to the pattern maker, who makes a model in wood from it (if it is to be a casting). From his experience he makes proper allowance for "shrinkage" of the casting during cooling, for "finishing" and for a certain amount of taper for "draft" in withdrawing the pattern from the mold.

The pattern is then sent to the foundry to be molded in sand. The form is filled with melted ore from the cupola. After the casting has cooled off, it is sent to the machine shop to be drilled, tapped, finished or whatever the drawing calls for, for the machinist must strictly follow all instructions, dimensions and notes contained in the drawing, thereby placing all the responsibility of error upon the draftsman.

This same strict rule applies to all working drawings, whether used in the machine, structural, woodworking or building trade.

Sketching.—When making drawings of a machine it would be inconvenient to carry board and instrument into the shop. The draftsman therefore is called on to make "sketches," carry them to the drafting room and make his drawings from them.

Each piece of the machine should be sketched separately and a complete working drawing made of it. After each piece has been sketched, make a rough general sketch of the whole machine, to show how the various pieces fit together, a few of the most important over-all dimensions, distances between centers, etc.

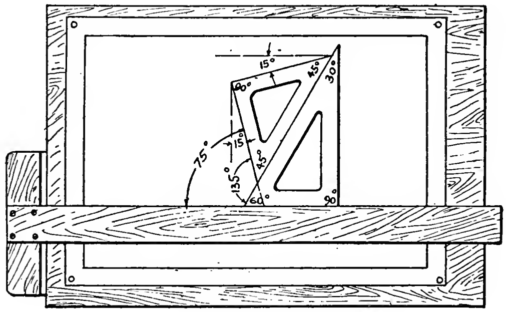
Before starting to sketch a piece, decide what views are necessary to describe the piece clearly. Make large sketches.

The sketches should be neat and perfectly clear. They should be done wholly *free hand,* except perhaps large circles and long lines.

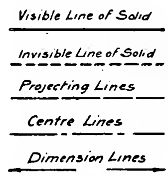
Use blank paper (no cross-section paper) for sketching, *don't draw to scale,* but place all dimensions, measured from the machine, on the sketch.

C—Laying Out Sheet and Lettering.

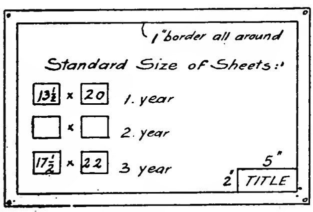
Size of Drawing Board and Paper.—The size of drawing board has been suggested by the author as follows: All plates except those of Chap. VI on board 16 $\times$ 23 (or there-



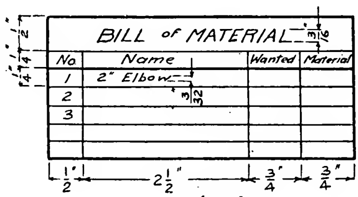
— Fig. 1. —



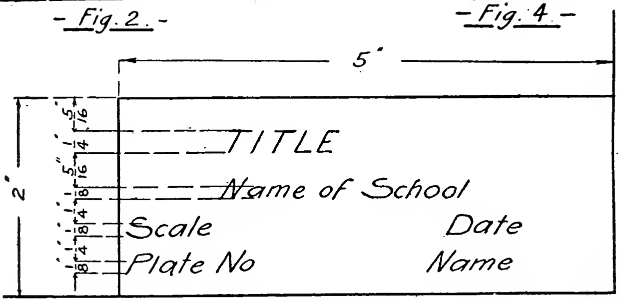
— Fig. 5. —



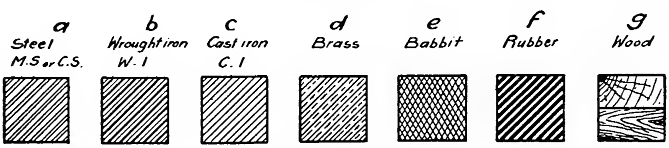
— Fig. 2. —



— Fig. 4. —



— Fig. 3. —



— Fig. 6. —

about) with paper 13½ × 20. These plates have been carefully laid out to suit this size of paper.

For the plates of Chap. VI a somewhat larger board is recommended (20 × 26) with paper 17½ × 22, and all plates of Chap. VI are laid out accordingly.

Border Line (Fig. 2).—Draw border line one inch wide all around. Paper should not be trimmed. Never mind exact dimensions within border line!

Title (Fig. 3.—Every drawing, beginning with the first one, must have a title, consisting of Name of Object, Scale, Date, Plate No. and name of draftsman indicating year and course of study.

Bill of Material (Fig. 4).—Each working drawing (not projection drawing) containing more than one part, must have a Bill of Material, stating name, material and number wanted of each item on the drawing. Each part may have its own sub-title, or it must be numbered to correspond with number on Bill of Material. In actual practice each casting must also have a pattern number.

Laying Out Drawing.—In laying out a drawing it is advisable to determine roughly the over-all dimensions of your drawing, so that it may be placed on the sheet with nearly equal margin all around. Always start from center lines. They not only make the start of any machine drawing easy, but they are also very important, as many dimensions are given from the center lines. For every part, that has a center, center lines must be shown, which also are to be inked in. When starting a plate first draw the principal axes of symmetry and then build gradually around them. This also applies to rivets, bolts, shafts and all circular and cylindrical work.

Round Writing.

abcdefghijklm n o p q r $\frac{1}{4}''$ for Pen No $2\frac{1}{2}$
s t u v w x y z.

Prism.

A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z.

— Gothic Letters —

ABCDEFGHIJKLM
NOPQRSTUVWXYZ
1234567890

abcdefghijklmn
opqrstuvwxyz

– Block Letters –

ABCDEFGHI
JKLMNOPQ
RSTUVW
XYZ

After the drawing is completed in pencil, the drawing is either traced or inked in.

Observe strictly the order of inking: Arcs, circles, straight lines, center lines, dimension lines, section lines, notes, title.

Lettering.—The appearance of a drawing is greatly improved by good printing or lettering. Most text-books, however, devote entirely too much space to this subject, showing all kinds and types of letters, difficult to execute and requiring a great deal of time, but which would not be tolerated in any drafting room, and may be of sole use to the sign painter. A good draftsman should make his letters *free hand* (unless ruled block-letters are required), and he should practice the two kinds most in use, "Gothic Letters" and "Round Writing," see plate on lettering. Gothic letters may be used either in capitals or small letters, or both combined.

Round writing has the advantage of taking little time and affording a wide range of size of letters due to the different sizes of pens. Round writing always looks good and is very easily mastered. *Practice with pen No.* 2½ (don't forget clip over pen!), making the small letters ¼", the capitals ⅜" high.

D—Important Rules as to Working Drawings.

The following rules should be studied very carefully. They become of more importance after the first few plates, when they will be better understood. But from the very beginning reference is made to these rules, and whenever this is done the student must study them and strictly adhere to them in his work.

Rule 1. Conventional Lines.—Use only the following five lines (Fig. 5):

(*a*) Visible line of solid—heavy full line (or light and heavy in case of shading).

(*b*) Invisible line of solid—medium heavy broken line.

(*c*) Projecting lines—light broken line.

(*d*) Center line—light dash and dot.

(*e*) Dimension lines—light full line.

Rule 2. Shade Lines.—They are not essential and not allowed on working drawings by most employers. They take up more time, but improve the appearance of the drawing. The light is assumed to come from the upper left hand corner at 45° in both plan and elevation (different from the rules of "Shades and Shadows"). Shading should be studied from the finished drawings in this book. Outlines of solids of revolution (cylinder, rod, bolt, etc.) as a rule are not shaded.

Rule 3. Scale.—Single machine parts are drawn to as large a scale as possible (full size preferably), depending, however, on space available. Use only the following scales:

Full Size, Half Size, 3″ = 1 ft. (¼ size), 1½″ = 1 ft. (⅛ size), 1″ = 1 ft. (1/12 size), ¾″ = 1 ft. (1/16 size), etc. (Found on the triangular boxwood scale.)

Rule 4. Dimensions.

(*a*) Every item represented on the drawing should be fully dimensioned.

(*b*) The dimensions are those of the object, no matter what the scale may be. They are given in feet, inches and fractions of an inch.

(*c*) Over 24″ express in feet and inches.

(*d*) Horizontal and vertical dimensions have the direction of their dimension lines and should be written as indicated on Plate 1. Note that fraction line coincides with dimension line. Note sharpness of arrows.

(*e*) Dimension lines must not cross each other.

(*f*) Show diameters (D. or dia.) in preference to radii (R. or rad.).

(*g*) Never cross-hatch over dimensions.

Rule 5. Sections.

(*a*) Working drawings are generally shown partly in section to show details of construction and form of casting, see Prob. 1, Plate 3.

(*b*) Indicate kind of material by cross-hatching the areas as shown in Fig. 6.

Fig. a.—Steel of all kinds.

Fig. b.—Wrought iron.

Fig. c.—Cast iron. When lines are drawn further apart, it may represent brick in section.

Fig. d.—Brass and other similar copper alloys.

Fig. e.—Babbitt, lead and similar soft metals.

Fig. f.—Rubber, vulcanite and wood fiber.

Fig. g.—In upper half: wood, when cut across the grain, in lower half: when cut along the grain.

(*c*) Where different parts join in one view, the section lines are shown at right angles to each other. (See Cylinder in Fig. 7.)

(*d*) All parts of the same piece must be sectioned in the same direction.

(*e*) Sections that appear too thin, such as boiler plates, structural sections, etc., are often blackened in. In order to separate different pieces, a white line is usually left between them. Direction of light as in Rule 2.

Rule 6. Finished Parts.—Finished parts are indicated by letter *f*. (See Plates 8 and 9.) If all is finished, state so by writing a note "finished all over." Some draftsmen prefer to draw a *red line,* where parts are to be finished. The "finishing" consists of machining the surface of the object, which according to the nature of the object may be accomplished by planing, facing, turning, boring, or scraping.

Rule 7. Cross-Sections.—Where in a sectional view the

cutting plane passes through one of the following parts they should not be shown in section: Spokes, arms, ribs, bolts, rivets, valve stems, shafts, rods, etc. (Fig. 7.)

Rule 8. Breaks.—Parts of considerable length are often shown broken. The break should indicate the shape of the object. Conventional methods of breaks are shown in Fig. 8.

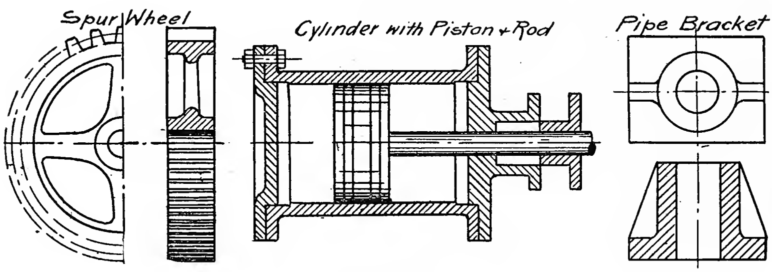


FIG. 7.

Rule 9. Symmetrical Work.—In case of symmetrical work, mostly end views, consisting of a number of concentric circles, frequently only one-half of the view is shown, Fig. 9.

Rule 10. Repeated Parts of Objects.—Where a flange is to be drilled for a large number of holes, only a few may be

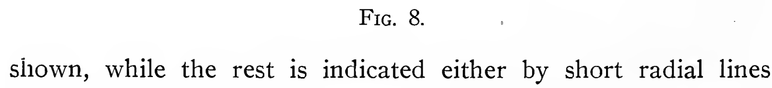


FIG. 8.

shown, while the rest is indicated either by short radial lines or a note to that effect.

Similarly in a gear-wheel, where only two or three teeth need be shown and the total number be specified in a note (unless the instructor decides to have all teeth shown). Also,

in riveted work only a few rivets may be shown, while the location of the rest is indicated by a suitable note.

Rule 11. Abbreviations.—The following terms may be found on shop drawings:

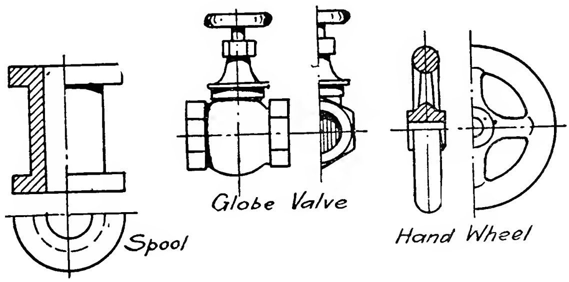


FIG. 9.

(*a*) 14 th'ds = 14 threads per inch (mostly referring to pipe threads.)

(*b*) 1″ tap = hole to be tapped (threaded) to fit a 1″ bolt.

(*c*) Drill = hole through object is drilled instead of cored (more accurate).

(*d*) Cored = hole through object is cored out (by pattern maker) and is not to be finished (drilled).

(*e*) Fillet = this term applies to castings whose concave corners are rounded out (filled) to insure greater strength and smoother work in moulding.

CHAPTER II.

SIMPLE WORKING DRAWINGS.

A—Three Views and Isometric.

Mechanical drawing is the art of making drawings capable of representing mechanical structures as a whole and in detail so clearly that skilled workmen can make them without further information, relying entirely on such information as given on the drawing.

Each object is represented in two or more views, fully dimensioned.

The Three Views.—In Fig. 10 a picture of a simple model is shown. *A* is the front surface, *B* the top surface, and *C* the

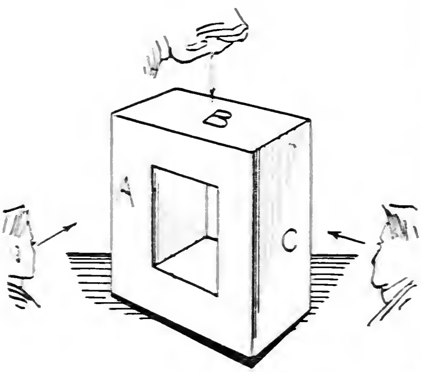


FIG. 10.

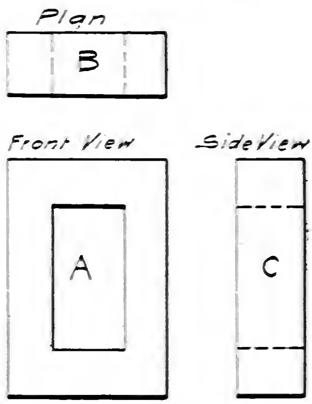


FIG. 11.

side surface. If we look in the direction of the arrows at the front surface *A* we obtain a front view *A*; by looking at the top surface *B* we obtain a top view (or plan) *B*, and by looking at the side surface *C* we obtain a side view *C*. These three views are shown in Fig. 11.

The top view *B* is shown above the front view *A* and the side view *C* to the right side of *A*.

Any surface of the object may be called the front view, provided the other views are drawn in the proper relation to this view. Generally the principal and larger view is chosen as the front view.

In working drawings these three views would not be sufficient unless they are fully dimensioned. See Prob. 1, Plate 1. This enables the mechanic to work from the drawing without taking refuge to scaling the drawing.

Simple and particularly symmetrical models may be represented in only front view and top view. Occasionally a very irregular object required special views in addition to the three views mentioned. For practice sake from the very beginning each

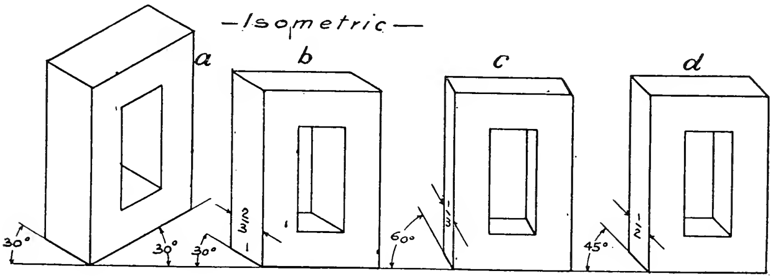


Fig. 12.

object should be represented in the three principal views mentioned above.

Isometric.—The "Isometric" of an object is a "one view" drawing of the three dimensions, height, breadth and thickness. "Isometric" means equal distances, that is, all lines, which are parallel, are drawn parallel contrary to a "Perspective," where all lines converge.

In practice a simple method to draw the Isometric is employed. Taking as an example a prism, Fig. 12a, the edges of both faces are inclined at 30° to the horizontal. Further-

more, all inclined lines are drawn full length, which, of course, never appears as such to the eye.

Another more simple method, which should only be employed when the object is too complicated, is the so-called *Oblique Isometric,* Fig. 12 *b, c, d.*

Here one face of the object is represented as a correct front view and all lines in the front face are shown in their true lengths. Any angle may be assumed for the edges of the other faces.

To approach somewhat real conditions, the following proportions are suggested:

Edges drawn at 45° to horizontal—half of full dimension.

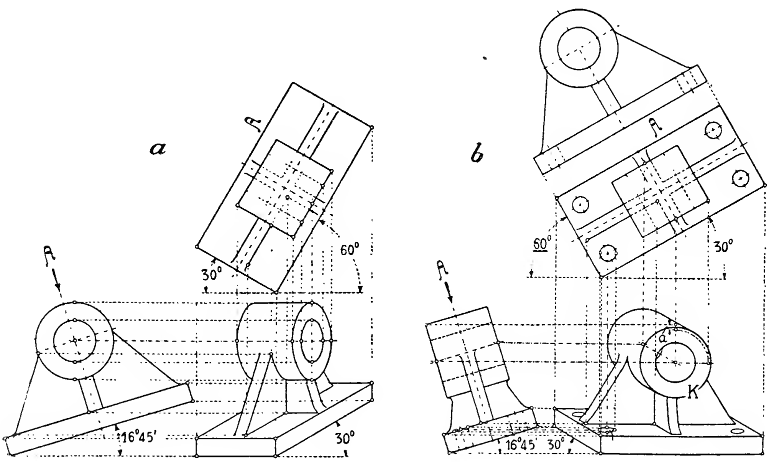


FIG. 13.

Edges drawn at 30° to horizontal—two-third of full dimension.

Edges drawn at 60° to horizontal—one-third of full dimension.

This rule applies also to the first method of drawing the Isometric.

A third method, more difficult, but more accurate and more pleasing to the eye is by means of Projection. In Fig. 13 the Isometric is obtained by Projection from two views of a Pillow block. Both views are inclined in such a way as to have one face of the object become horizontal while the other face makes an angle of 30° with the horizontal. The angle of 16° 45′, which the base of the auxiliary view makes with the horizontal, has been found by computation. In Fig. 13_b, the cylindrical part *K* of the pillow block ought by projection appear as an ellipse in the Isometric. As this ellipse, however, is of nearly circular form, it is replaced by a circle by splitting the small difference a.

B—Simple Models.

On Plates A, B and C a number of models is shown in form of pictures, which in the absence of suitable models are to be used as problems for the first three drawing plates (optional with Instructor to expand work into more plates).

Plate 1. Wooden Models.—Make a working drawing of three views of three solids assigned by Instructor from Plate A. Scale full size. Find suitable title for each model. Make list of material. Observe strictly rules 1, 2, 4_a, 4_e.

Plate 2. Metal Models.—Make working drawing of three views and Isometric of two solids assigned by Instructor from Plate B. Scale full size. Find suitable title for each model. Choose kind of material. List of material. Observe same rules as in Plate 1.

Plate 3. Machine Details.—Make working drawing of three views and Isometric of two solids assigned from Plate C. Scale 6″ = 1 ft. Find suitable title for each model. Choose kind of material. List of material. Observe strictly rules 1, 2, 4_b, 4_a, 4_e, 4_g, 5_a, 5_b.

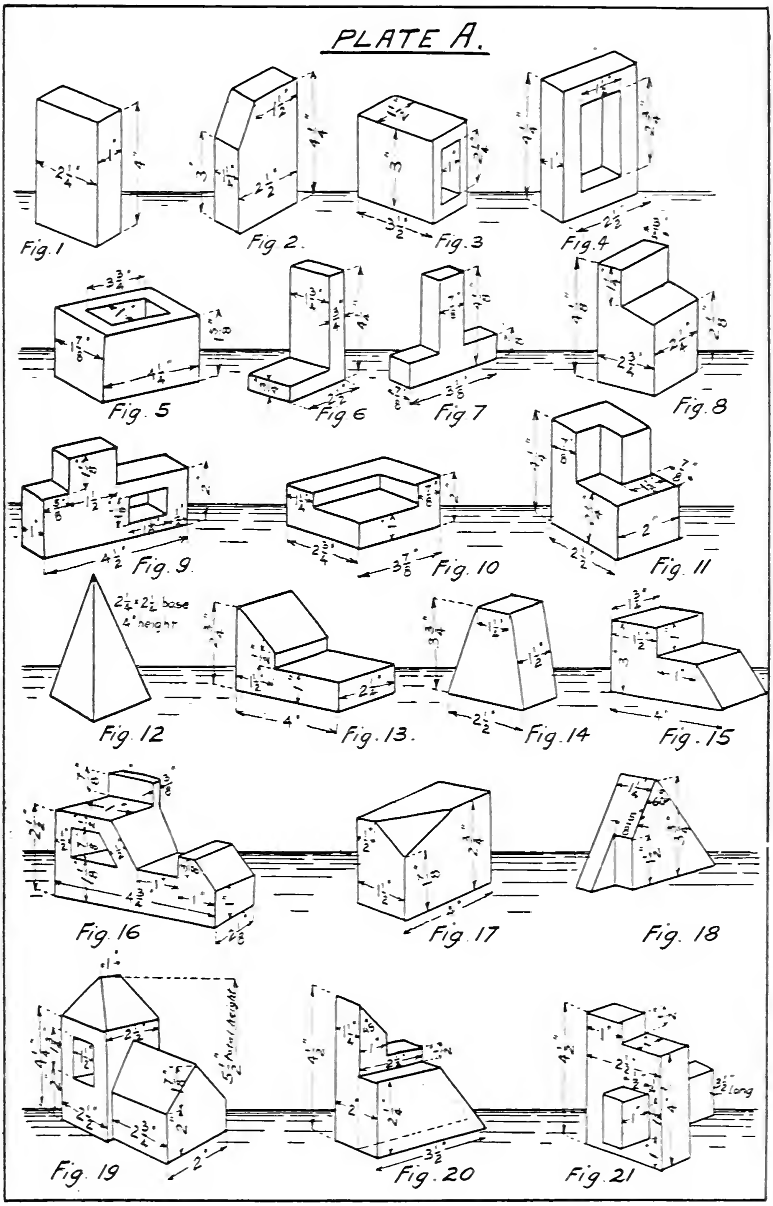


PLATE A.
Fig. 1
Fig. 2.
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Fig. 8
Fig. 9.
Fig. 10
Fig. 11
$2\frac{1}{4} \times 2\frac{1}{4}$ base
4" height
Fig. 12
Fig. 13.
Fig. 14
Fig. 15
Fig. 16
Fig. 17
Fig. 18
Fig. 19
Fig. 20
Fig. 21
$3\frac{1}{2}$" long
$5\frac{1}{2}$" Actual height

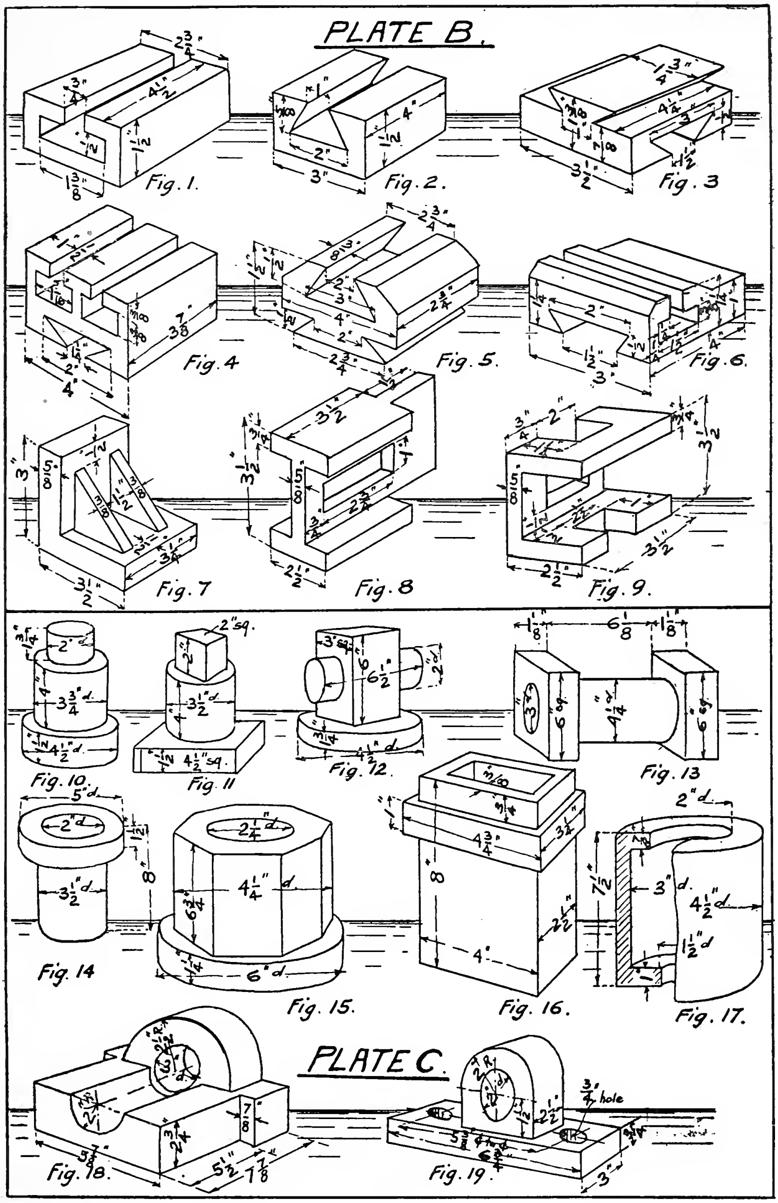
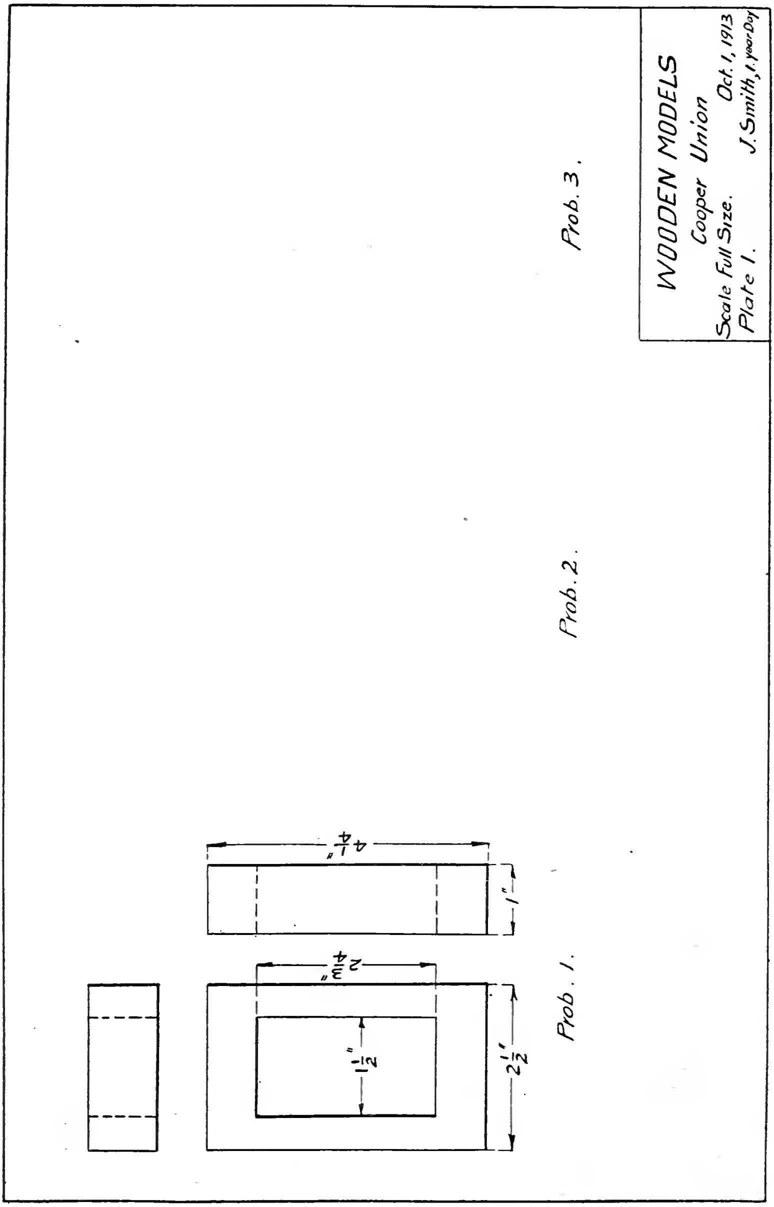


PLATE B.
Fig. 1.
Fig. 2.
Fig. 3
Fig. 4
Fig. 5.
Fig. 6.
Fig. 7
Fig. 8
Fig. 9.
Fig. 10.
Fig. 11
Fig. 12.
Fig. 13
Fig. 14
Fig. 15.
Fig. 16.
Fig. 17.
PLATE C.
Fig. 18.
Fig. 19.


WOODEN MODELS
Cooper Union
Scale Full Size.
Oct. 1, 1913
Plate 1.
J. Smith, 1. year Day
Prob. 3.
Prob. 2.
Prob. 1.
4 1/4"
1"
2 3/4"
1 1/2"
2 1/2"

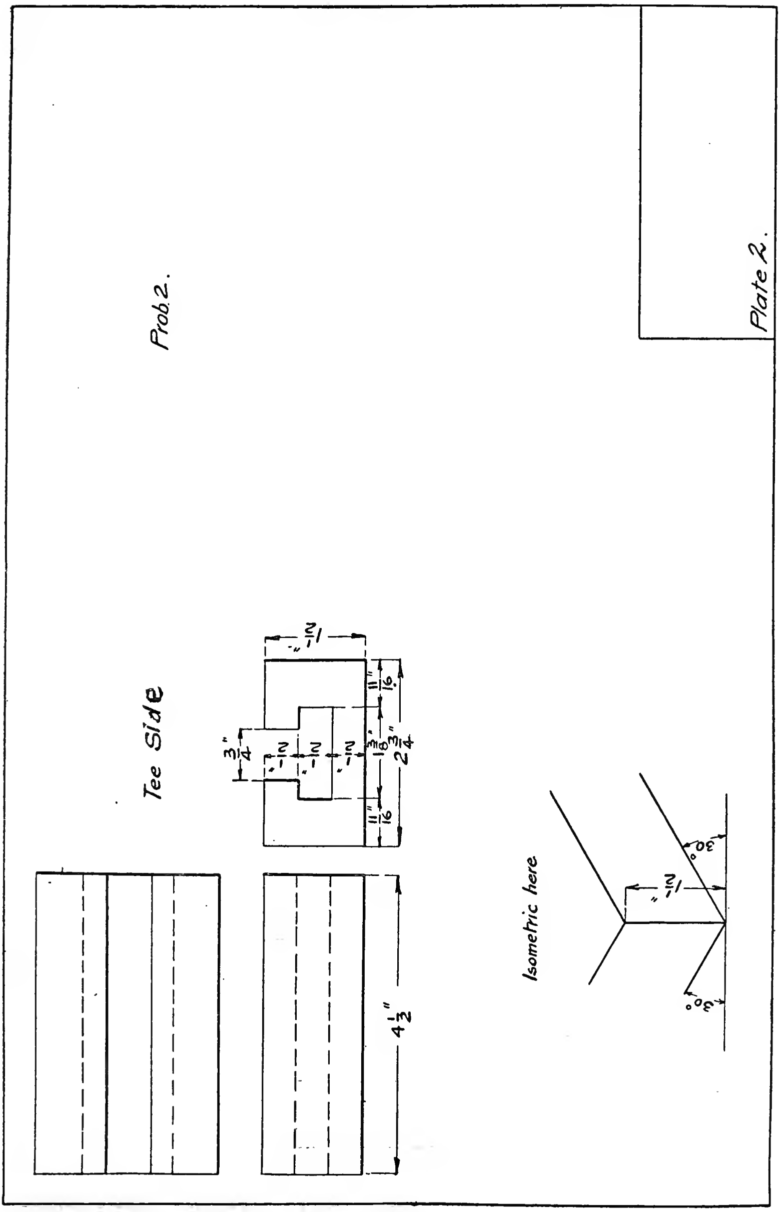


Plate 2.
Prob. 2.
Tee Side
Isometric here
30°
30°
4½"
2¾"
1½"
¾"

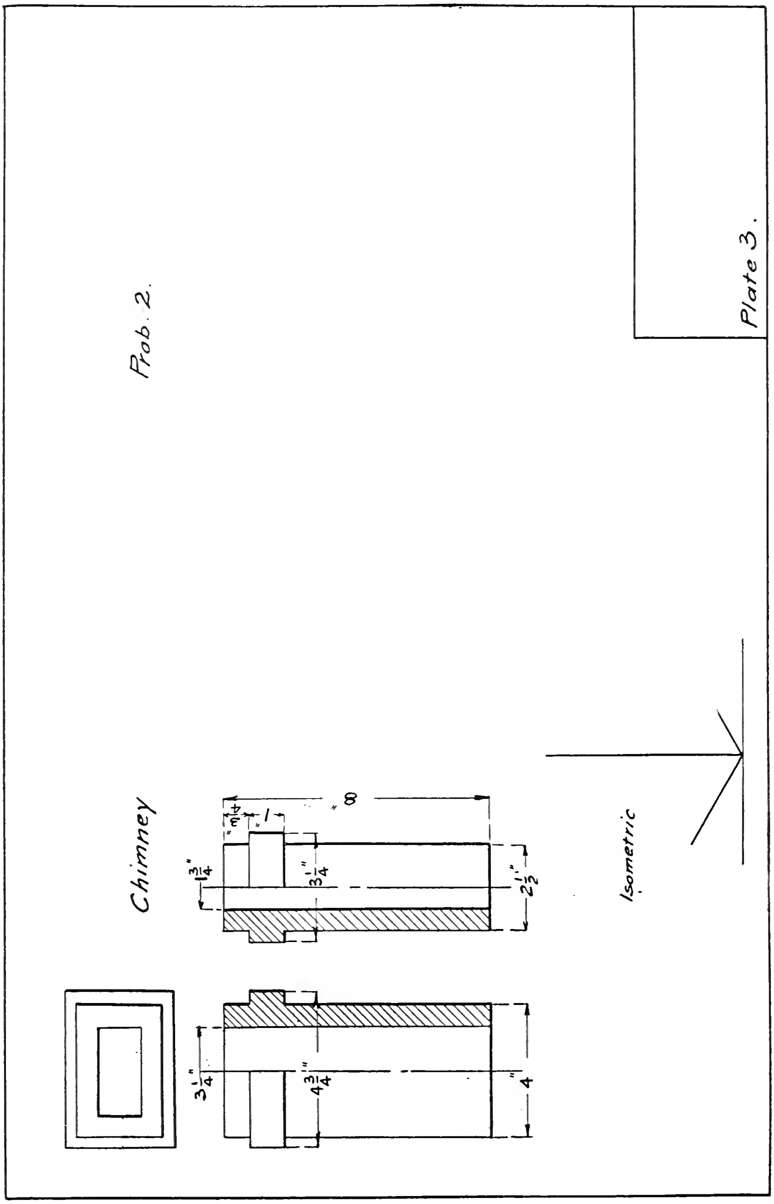


Plate 3.
Prob. 2.
Chimney
Isometric

C—Wooden Joints and Carpenter Work.

On Plate D a number of points used in wood-working are shown, which, in the absence of suitable models, may serve as drawing problems for Plate 4 (also suitable for two plates).

On Plates 5 and 6 wooden structures are shown, where such joints are employed.

Plate 4. Wooden Joints.—Make working drawing of three views and Isometric of two wooden joints assigned by instructor from Plate D. Scale 6″ = 1 ft.

List of material.

Plate 5. Frame Work.—Make working drawing of three views and Isometric (shown already on printed plate) of the frame-work. Scale ¼″ = 1 ft. Make list of wooden joints employed, and indicate same with letters in the frame-work.

Plate 6. Drawing Table.—Make working drawing of three views and Isometric of drawing table. (Instructor may substitute other table or chest, etc., in drafting-room.) Scale 1½″ = 1 ft. Copy drawing carefully from printed plate.

D—Machine Drawings.

The most important part of any machine is the machine bolt.

Conventional ways of representing bolt threads are shown in Fig. 14.

a. Double V thread.
b. Single V thread.
c. Single square thread.
d. Single L. H. V thread.
e. Double R. H. Sq. thread.
f. V thread for small bolts.
g. Any thread for very small bolts.

There are a large number of special bolts in use. Be sure to remember the three most important ones: the "through bolt,"

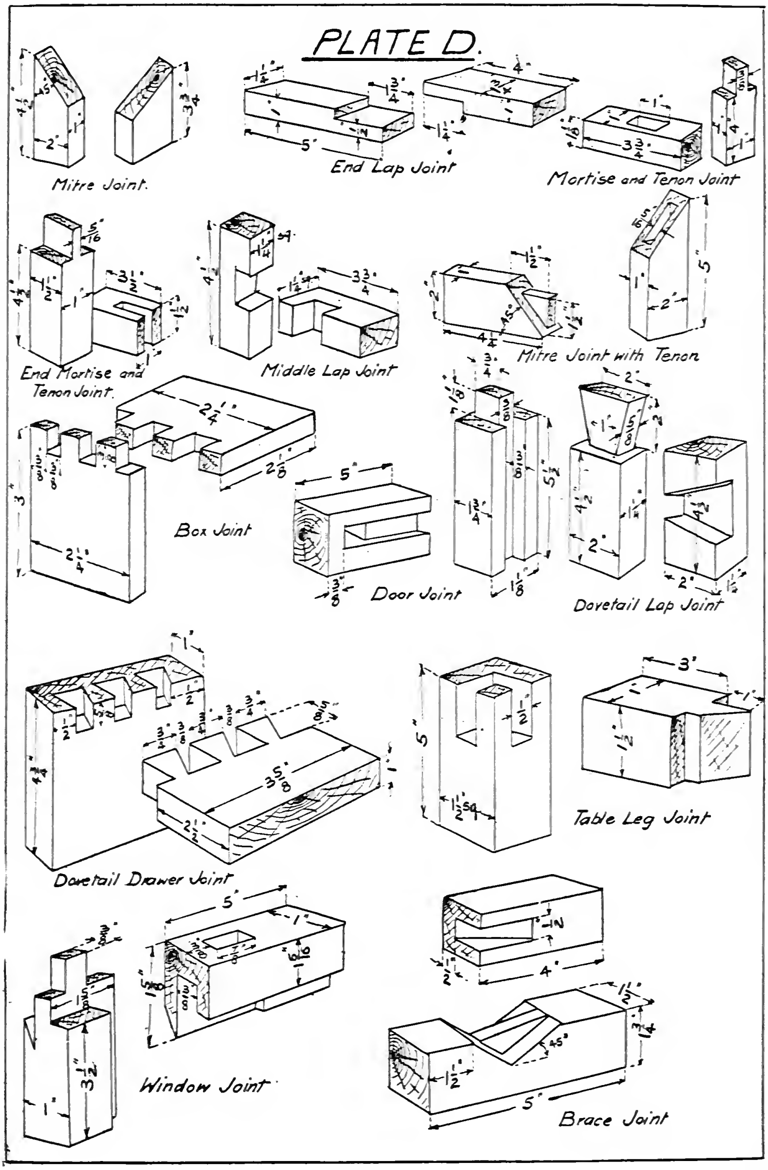
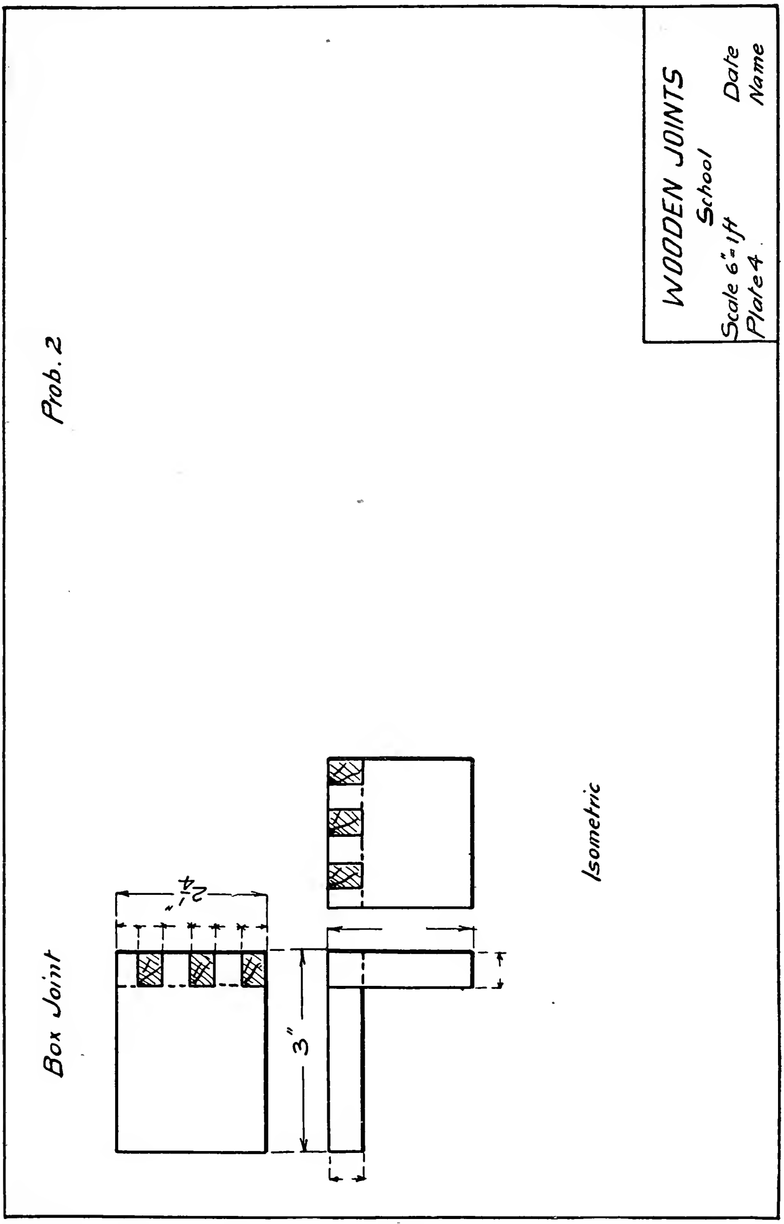
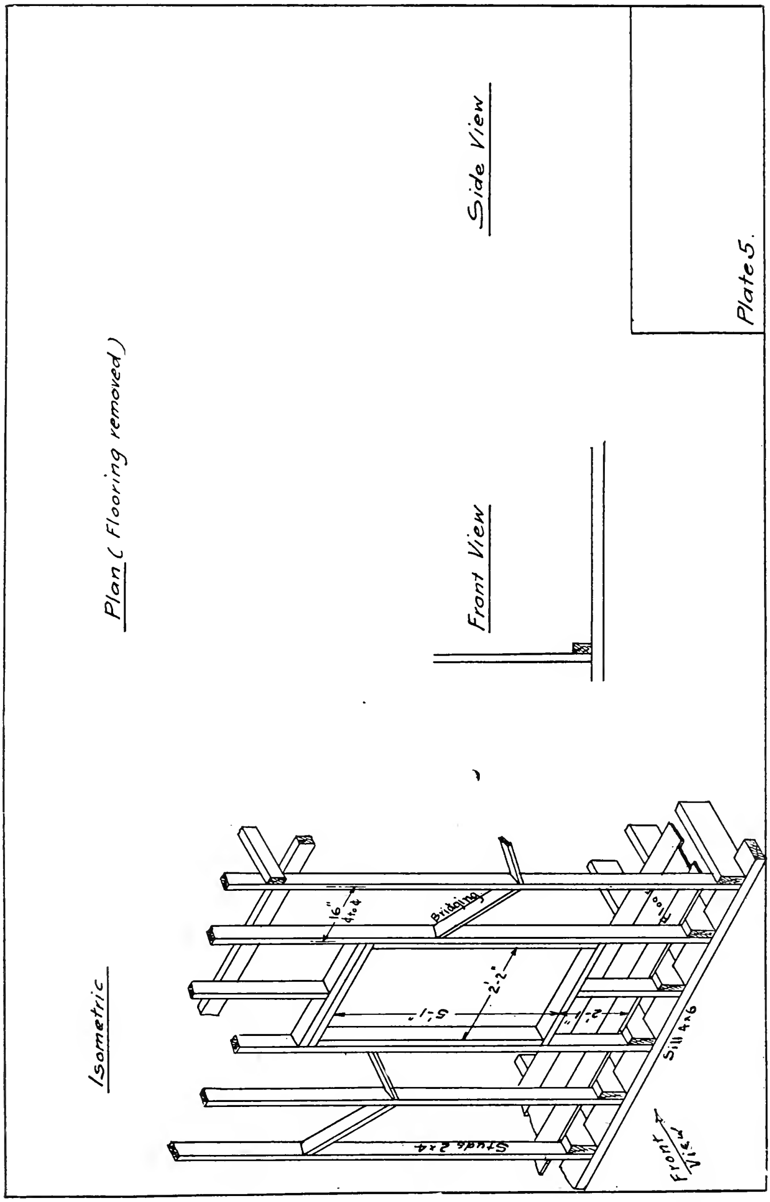


PLATE D.
Mitre Joint.
End Lap Joint
Mortise and Tenon Joint
End Mortise and Tenon Joint.
Middle Lap Joint
Mitre Joint with Tenon
Box Joint
Door Joint
Dovetail Lap Joint
Dovetail Drawer Joint
Table Leg Joint
Window Joint
Brace Joint


WOODEN JOINTS
School
Scale 6" = 1 ft
Plate 4
Date
Name
Prob. 2
Box Joint
Isometric
3"
2¼"


Isometric
Plan (Flooring removed)
Front View
Side View
Plate 5.
Studs 2x4
Sill 4x6
Bridging
16"
2'-2"
5'-1"
Front View

"stud bolt" and "tap bolt," shown on Plate 7. Below is given a table of standard bolts and nuts.

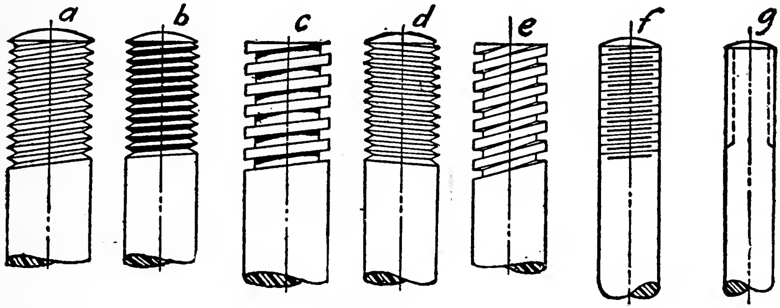


FIG. 14.

Plate 7. Bolts and Nuts.

(a) Correct way of representing threads:

1. 3″ V threaded screw and nut.
2. 3″ square threaded screw and nut.

Standard Bolts and Nuts.

d = dia. of bolt, D = distance across corners of hexagonal Nut.
N = Number of th'ds p. inch

d	1/4	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	1 3/4	2	2 1/2	3
D	37/64	51/64	1	1 7/32	1 7/16	1 7/8	2 5/16	2 3/4	3 3/16	3 5/8	4 1/2	5 3/8
N	20	16	13	11	10	8	7	6	5	4 1/2	4	3 1/2

Standard W. I. Pipes.

d = Inside Dia., D = Outside Dia., N = Number of th'ds p. inch

d	1/4	1/2	3/4	1	1 1/2	2	3	4	6	8	10
D	.54	.84	1.05	1.31	1.9	2.37	3.5	4.5	6.62	8.62	10.75
N	18	14	14	11 1/2	11 1/2	8	8	8	8	8	8

Taper of conical tube-ends 1 : 32 to axis of tube.
(3/4″ per ft. total taper.)

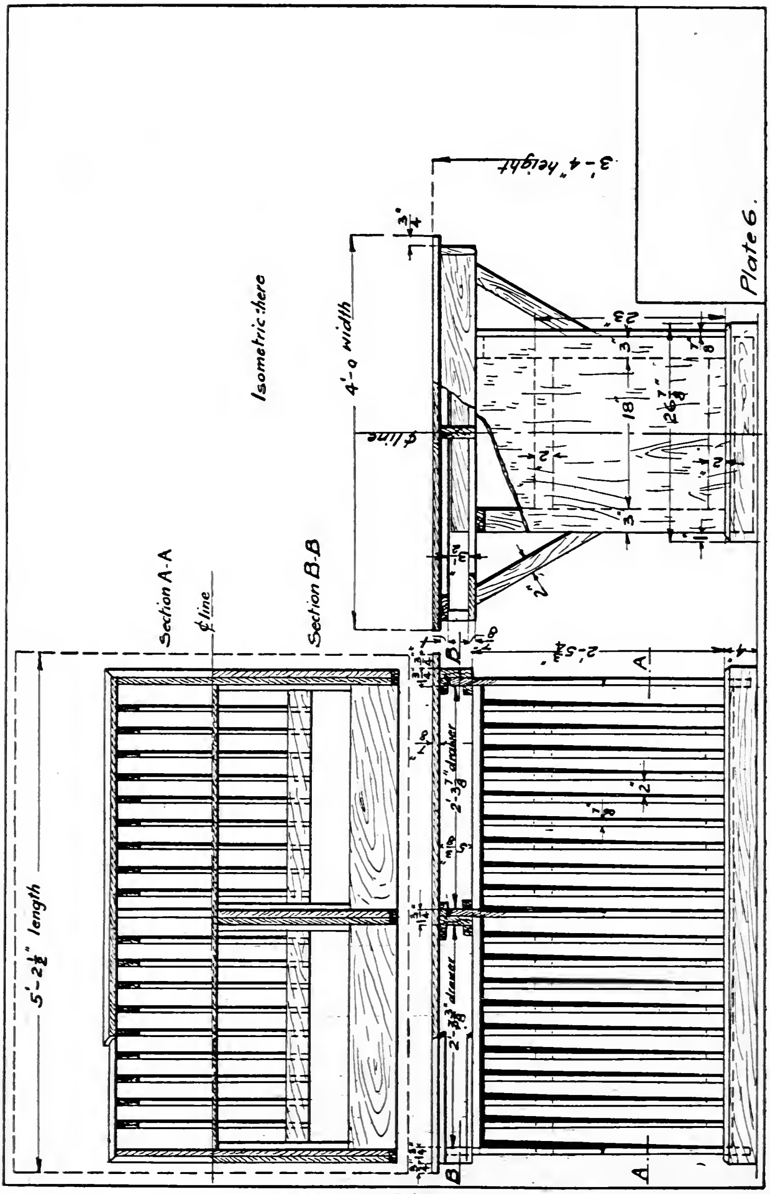


Plate 6.
Isometric here
Section A-A
Section B-B
¢ line
5'-2⅛" length
4'-0 width
3'-4" height
2'-3⅞" drawer

(b) Conventional way of representing threads and nuts:

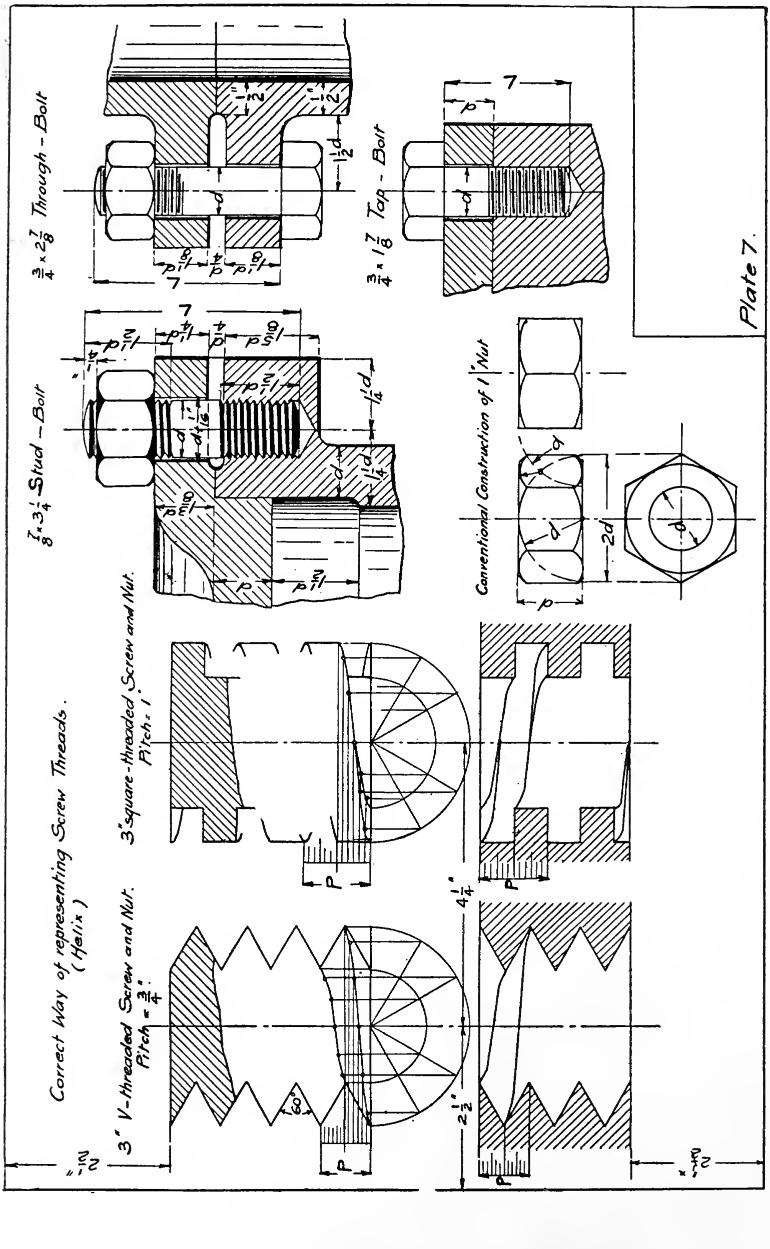
1. ¾ x 2⅞" through bolt.
2. ¾ x 1⅞" tap bolt.
3. ⅞ x 3¼ stud bolt.
4. 1" bolt nut.

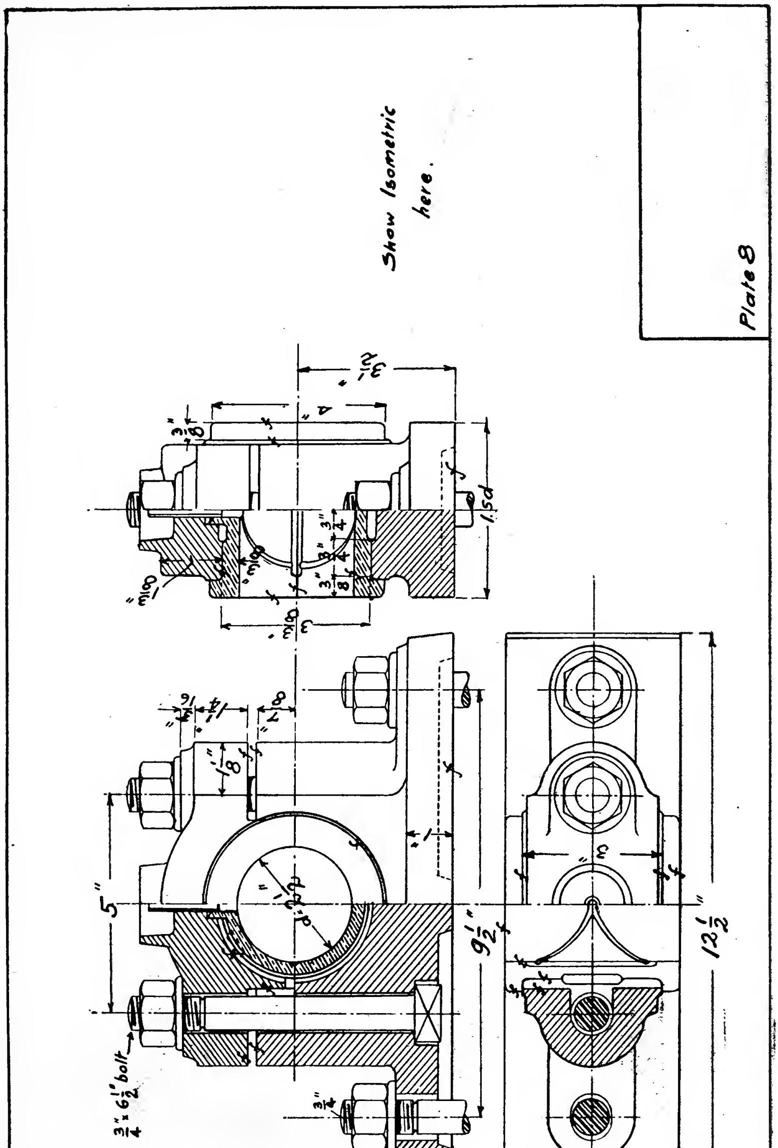
Scale, full size.

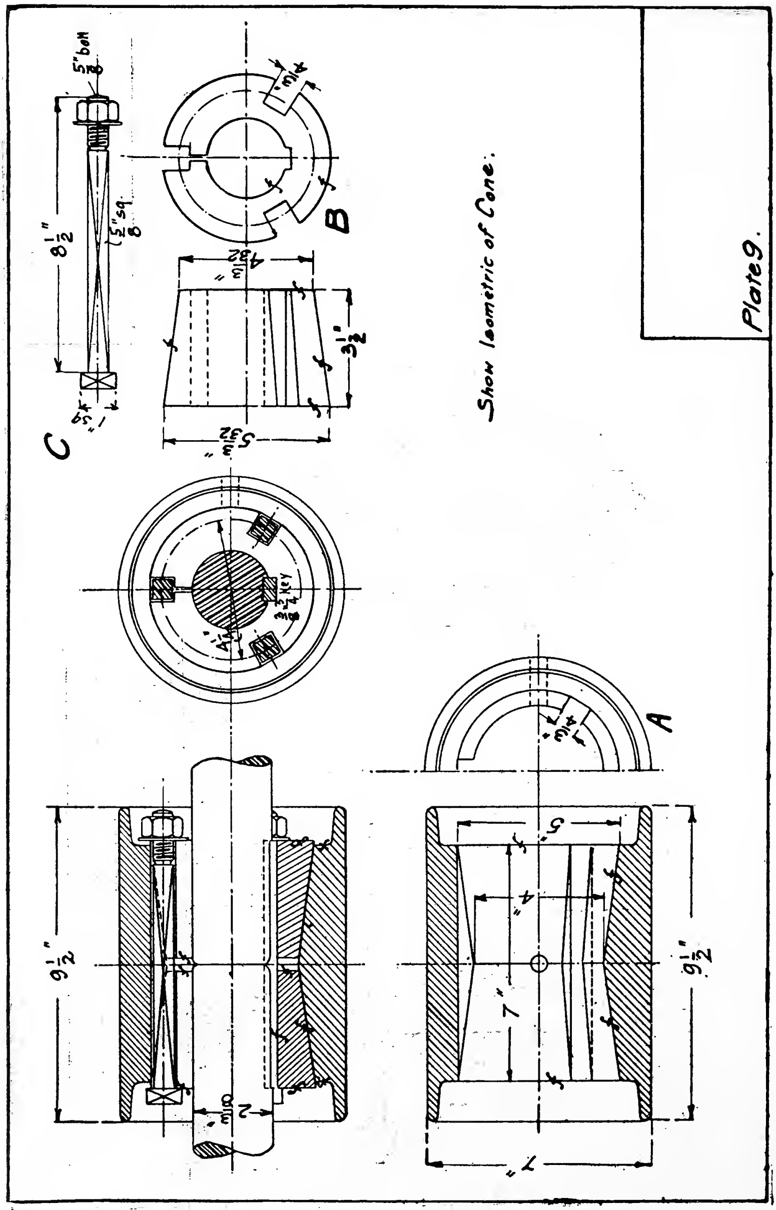
Make a careful copy of printed plate 7. The unfinished parts of the drawing have to be completed.

Plates 8 and 9.—The author strongly recommends at this point the use of larger machine models. Either of the following ones may serve as good objects: Shaft Coupling, Shaft Hanger, Pillow Block, Pulley, Bench Vise. Where no models can be obtained, make drawings of *Pillow Block* and *Seller's Shaft Coupling* from Plates 8 and 9. In connection with these plates study carefully the following rules: 4_f, 4_g, 5_a, 5_b, 5_c, 5_d, 6, 7, 8, 9, 11.

Plate 10. Pipe Work.—Make Isometric as shown on printed plate and three views. Scale, 3" = 1 ft. Before attempting this plate, make yourself thoroughly familiar with the various pipe fittings used here. *Don't fail to get Manufacturers' Catalog!*


3/4 × 2 7/8 Through - Bolt
7/8 × 3 1/4 Stud - Bolt
3/4 × 1 7/8 Tap - Bolt
Conventional Construction of 1" Nut
Plate 7.
Correct Way of representing Screw Threads.
(Helix)
3" square-threaded Screw and Nut.
Pitch = 1"
3" V-threaded Screw and Nut.
Pitch = 3/4"
60°


Show Isometric
here.
Plate 8
3/4" x 6 1/2" bolt
5"
9 1/2"
12 1/2"
1.5d


Show Isometric of Cone.
Plate 9.
A
B
C
$9\frac{1}{2}$"
7"
4"
$8\frac{1}{2}$"
$3\frac{1}{2}$"

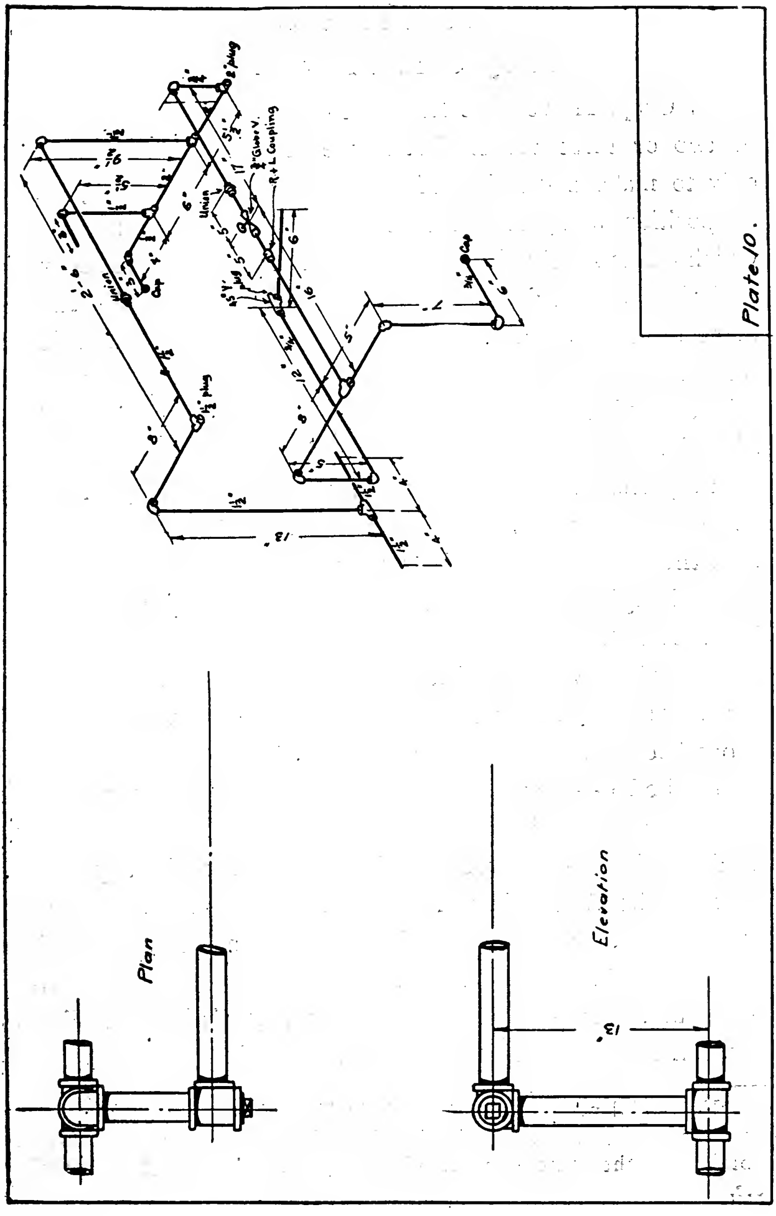


Plate 10.
Plan
Elevation
Union
Cap
R+L Coupling

CHAPTER III.

PROJECTION DRAWING.*

In Chap. II we have learned to represent objects by means of two or three views. When we are now called upon, not only to make a drawing of a solid, but also to clearly define its position in space, we take refuge in Projection Drawing, which treats Mechanical Drawing with mathematical accuracy.

While it is evident that the art of Mechanical Drawing must have as its foundation an exact mathematical science, we must bear in mind that for the practical draftsman this science is of secondary importance and only serves the purpose of easier mastering the principles of Mechanical Drawing.

Projection is the art of representing objects by views on two or three planes at right angles to each other in such a way that the forms and positions may be completely determined. These imaginary planes are called *planes of projection*, one being horizontal, the others vertical. The walls and floor of a room may serve as an illustration. The position of a book, for instance, lying on a chair may be defined as follows: 30″ above floor, 2 ft. away from rear wall, 3 ft. away from side wall.

Method 1.—If we call the floor Plane 1, the rear wall Plane 2, and the side wall Plane 3, we have Fig. 15a. If we now look at the solid in the direction of the arrows, as in Fig. 10, we observe the three views *A, B* and *C* on the three opposite planes. In ortographing projection we consider that all lines of sight producing the view are parallel to each other and perpendicular (ortographic) to the planes. As it is impossible to show the three planes of projection at right angles to each

*Note—All problems dealt with in Tinsmith and Boiler work are based on problems in Projection Drawing. The developments are obtained in the same way, allowing proper lap for soldering, riveting, etc.

other on the flat surface of the drawing board, it is necessary to imagine P_1, and P_2 revolved until all three planes form one plane, Fig. 15b.

By omitting the outer limiting lines of the planes we obtain the complete projection drawing of the solid, Fig. 15c.

Method 2.—If we imagine walls and ceiling to be transparent, in other words, if the solid is enclosed within a glass box, Fig. 16a, we can trace the three views *A, B* and *C* of the solids on the outside of the three glass panes, as they appear to the eye, and if we, like in Method 1, revolve P_2 and P_3 until they form one plane with P_1 we have Fig. 16b. The finished drawing appears in Fig. 16c.

By comparing Method 2 with Method 1, we notice that in the second method the views appear arranged to each other in the same way as we have learned in Chap. I, Fig. 11. In many drafting rooms this method is preferred, that is, the top view is shown above instead of below the front view, and the right side view is shown, where it is seen, viz., to the right of the front view. The student should understand that any of these two methods may be used in mechanical drawing. Most of the following problems have been worked out on the first method, as this method seems to be better adapted to the study of Projection Drawing.

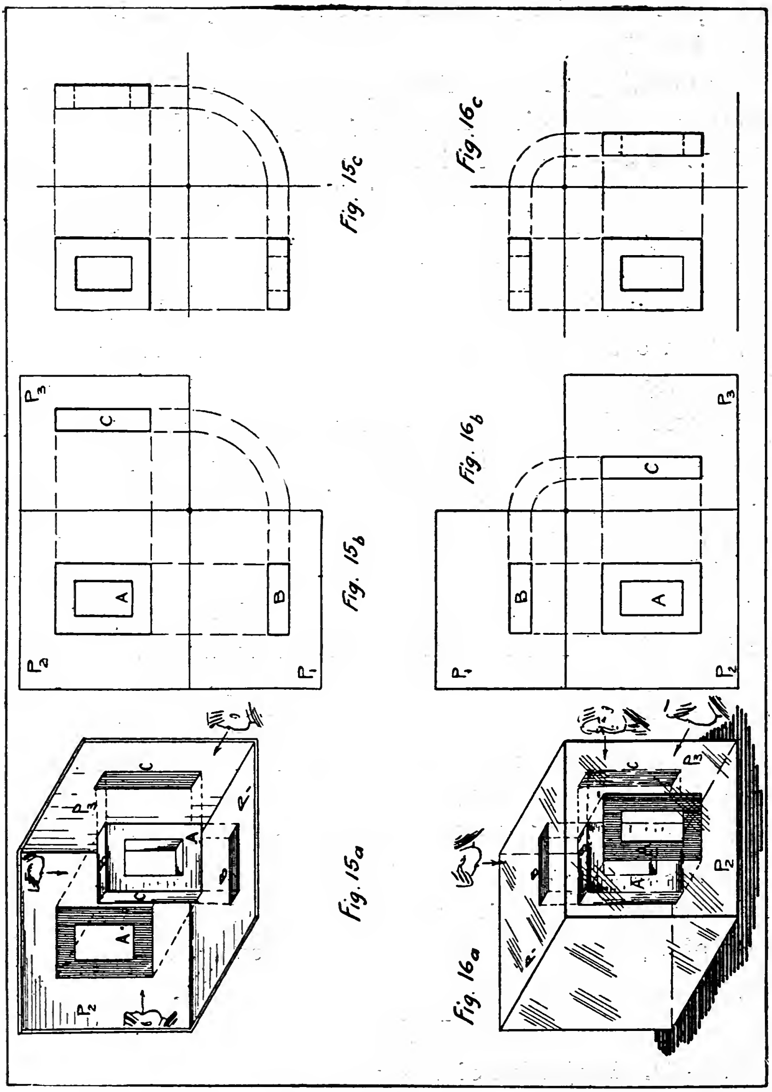
In Figs. 15c and 16c the dotted lines are called *projecting lines.* The points of intersection of projecting lines with the planes of projection are the *projections of the points.* The lines of intersecton of a plane with the planes of projection are the *traces of the plane.*

A—Projections.

Plate 11. Projection of Prisms.

Prob. 1. Hexagonal prism, 1⅝″ outside dia., 2¼″ high.

Prob. 2. Cube, 1⅜″ × 1⅜″.



FIGS. 15 AND 16.

Prob. 3. Cylinder, 1⅝" dia., 2¼" high.

Prob. 4. Irregular pentagonal prism, 2¼" high.

Three Views and Development.—Where positions are not specified, arrange views to suit space available. Missing dimensions, for instance, of base of Prob. 4 may be assumed.

Developments.—The surface of a solid extended or spread out on a plane in its true size and shape is called the *development of the surface.*

In order to find the development of a prism one of its sides is supposed to be placed in contact with some plane, then the prism turned on the edge, until all faces have been placed on the same plane. Then add top and bottom.

The development of a prism, then, consists of as many rectangles joined together as the prism has sides,—these rectangles being the exact size of the faces of the prism, and in addition two polygons the exact size of the bases.

Plate 12. Projection of Pyramids.

Prob. 1. Cone.

Prob. 2. Pentagonal pyramid.

Prob. 3. Hexagonal pyramid.

Prob. 4. Octagonal pyramid.

Three views and development. Circumscribing base circle 1½" dia., height = 2¼".

Developments.—A pyramid is developed by placing one of its sides on a plane surface, and rolling the pyramid on the plane, the vertex remaining stationary, until the same element is again in contact. The space rolled over will represent the development of the surface of the pyramids. All of the edges of a regular pyramid are of the same length.

From this it follows that *the development of the surface of a cone, for instance, is made by describing the arc of a circle of radius equal to the length of an element.*

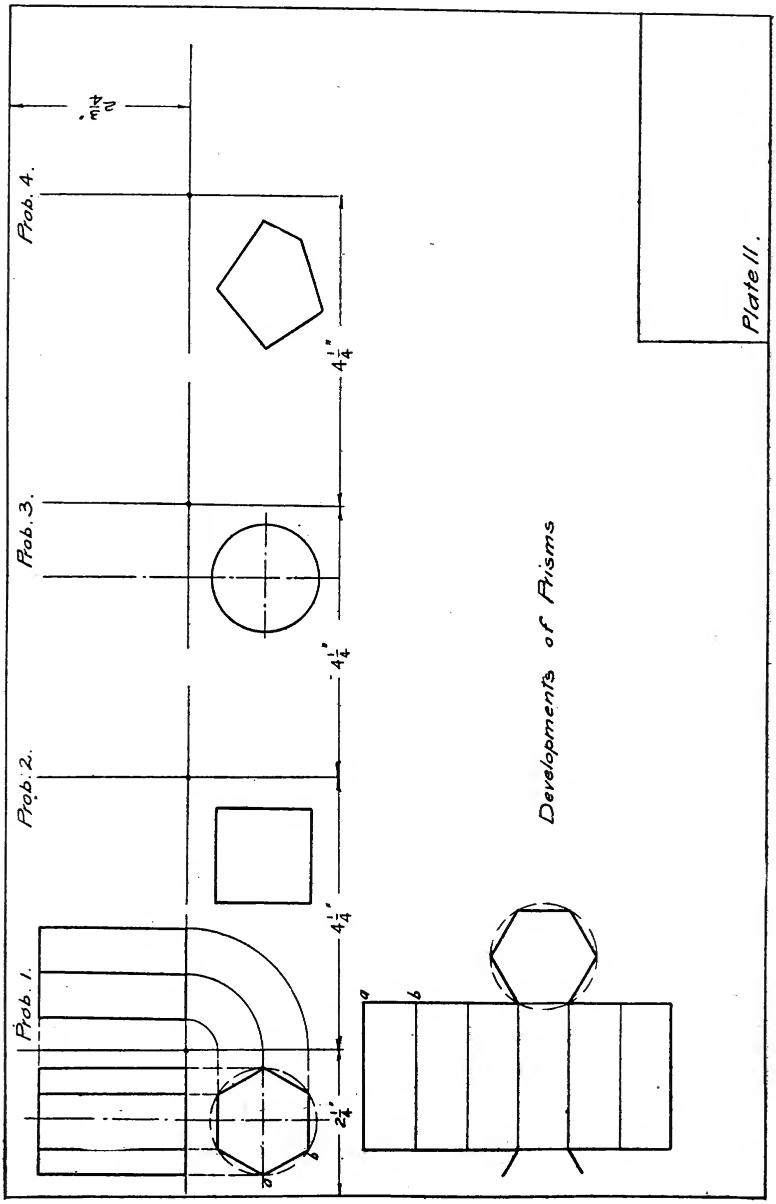

Prob. 1.
Prob. 2.
Prob. 3.
Prob. 4.
Developments of Prisms
Plate II.
4¼"
4¼"
4¼"
2¼"
2¼"
a
b

Plate 13. Inclined Prisms.

Prob. 1. Rectangular prism, 1¼″ × ½″ × 1⅞″ high.

Prob. 2. Hexagonal prism, 1¼″ base circle, 1⅞″ high.

Prob. 3. Cylinder, 1⅛″ dia., 1⅞″ high.

Prob. 4. Irregular pentagonal prism, 1⅞″ high.

Pos. a. Perpendicular **to** P_1 and parallel to P_2.

Pos. b. Inclined at $\alpha = 60°$ to P_1 and parallel to P_2.

Pos. c. Inclined at $\alpha = 60°$ to P_1 and $\beta = 30°$ to P_2.

Plate 14. Inclined Pyramids.

Prob. 1. Quadralateral pyramid, 1¼ x 1¼ base, 2⅛″ high.

Prob. 2. Hexagonal pyramid, 1⅜″ base circle, 2⅛″ high.

Prob. 3. Cone, 1⅜″ base circle, 2⅛″ high.

Prob. 4. Pentagonal pyramid, 1⅜″ base circle, 2⅛″ high.

Pos. a. Perpendicular to P_1 and parallel to P_2.

Pos. b. Inclined at $\alpha = 60°$ to P_1 and parallel to P_2.

Pos. c. Inclined at $\alpha = 60°$ to P_1 and $\beta = 45°$ to P_2.

B—Sections.

By "section" we understand any figure formed by the intersection of a solid and a cutting plane.

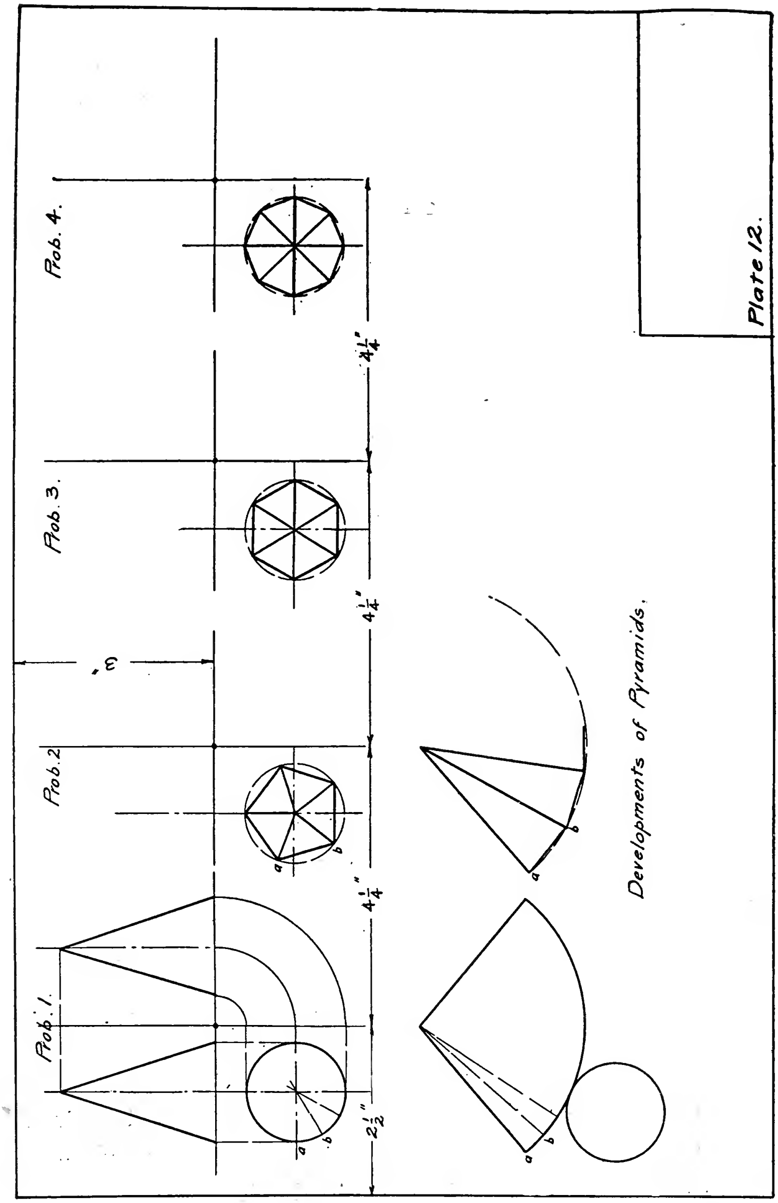
Plate 15. Sections of Prisms and Pyramids.

Prob. 1. Right cone, 1¾″ base circle, 2¾″ high, cut by plane parallel P_1 1¼″ above base.

Prob. 2. Irregular pentagonal pyramid, base within circumscribing circle of 1⅞″ diameter, 2¾″ high, cut by plane parallel P_1 1¼″ above base.

Prob. 3. Hexagonal prism, face nearest P_2, making an angle of 15° with P_2, 1¾″ outer diameter, cut by plane inclined to P_1 at 45°, perpendicular to P_2. Point of intersection with P_1 = 1⅛″ to left of axis of prism.

Prob. 4. Cylinder, 1¾″ diameter, 2″ high, cut by plane inclined to P_1 at 45° and perpendicular to P_2. Point of intersection with P_1, = 1⅜″ to left of axis of cylinder.


Prob. 1.
Prob. 2
Prob. 3.
Prob. 4.
3"
$2\frac{1}{2}$"
$4\frac{1}{4}$"
$4\frac{1}{4}$"
$4\frac{1}{4}$"
a
b
Developments of Pyramids.
Plate 12.

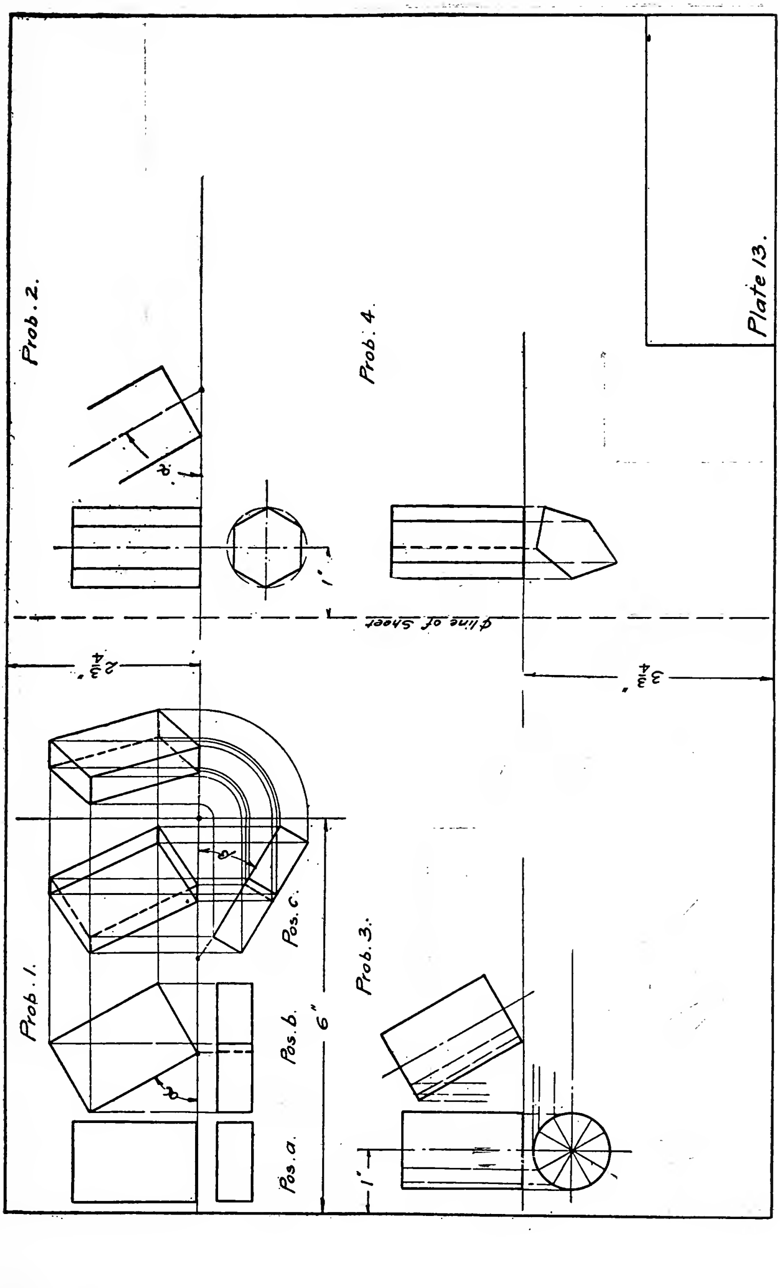


Plate 13.
Prob. 2.
Prob. 4.
Prob. 1.
Prob. 3.
Pos. a.
Pos. b.
Pos. c.
6"
1"
1"
2¾"
3¾"
℄ line of Sheet

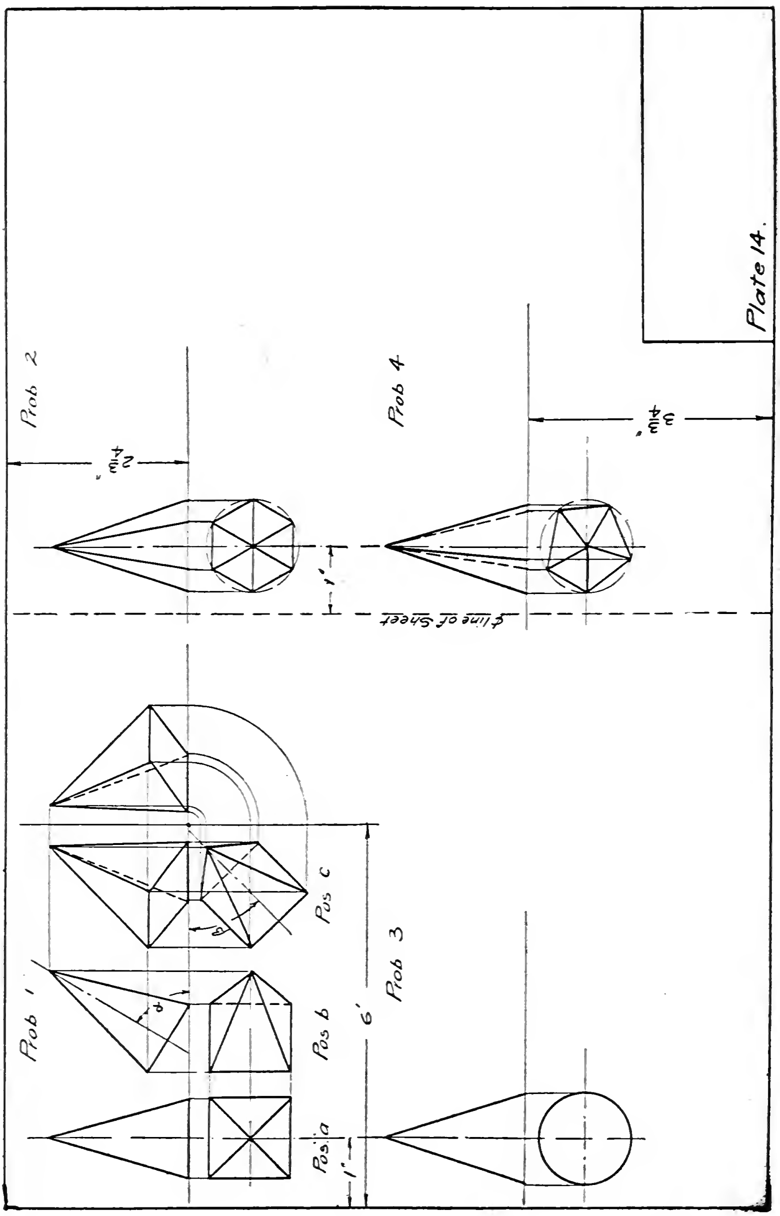
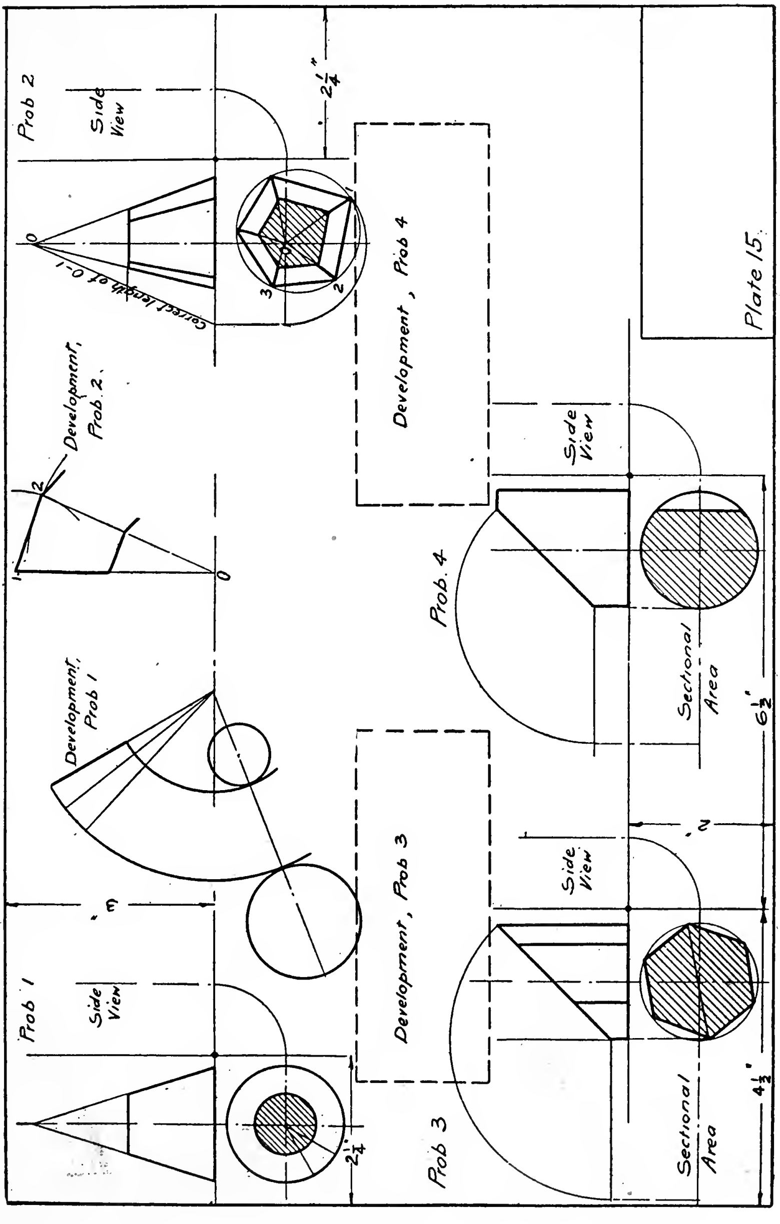


Plate 14.
Prob 1
Prob 2
Prob 3
Prob 4
Pos a
Pos b
Pos c
6'
1'
1'
2 1/4"
3 3/4"
℄ line of Sheet


Prob 1
Side View
Prob 2
Side View
Correct length of 0-1
Development, Prob. 2.
Development, Prob 1
Development, Prob 3
Development, Prob 4
Prob. 4
Prob 3
Side View
Side View
Sectional Area
Sectional Area
Plate 15.
2¼"
3"
2"
6½"
4½"

Three views and developments.

When a regular solid is cut by a plane parallel to its base, as in Prob. 1 and 2, the section is a figure similar to the base.

If the cutting plane is inclined to P_1, as in Probs. 3 and 4, the section will not be similar to nor of the same shape as the base, although it appears to the eye as such in the plan. The true sectional area, which would be perceived by looking at the section in the elevation at right angles, is found by revolving the cutting plane into a horizontal position and obtaining the points for the sectional area, where the projecting lines from the section and the plan view intersect. To find the development of the irregular pyramid in Prob. 2, find the true length of the edges, for instance, O—1, by revolving the plan view, until such edge is parallel to P_2. The new projection of the edge in elevation will show its true length. The development then is obtained by triangulation.

Conic Sections. Sections cut by a plane from a cone are defined as conic sections. These sections may be either of the following (Fig. 17.)

a. Circle. Plane parallel to base.

b. Triangle. Plane passes through vertex.

c. Ellipse. Plane inclined to base, cutting all elements.

d. Parabola. Plane parallel to one element.

e. Hyperbola. Plane parallel to axis.

These sections appear as straight lines in elevation, while in plan they appear with exception of case b as curves. To

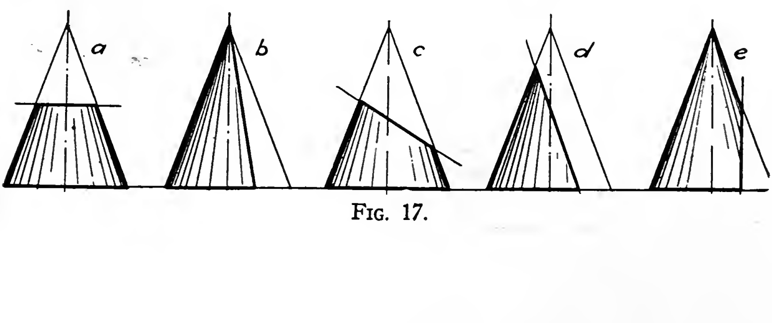


FIG. 17.

find points for these curves, we employ here for the first time the method of *auxiliary cutting planes.* Horizontal cutting planes passed through *solids of revolution* appear as circles in plan. And if the problem calls for the horizontal projection of a point shown in elevation on the surface of a solid of revolution, we pass an auxiliary cutting plane through this point and the intersection of this plane in Plan (as circle) with the vertical projecting line from the point in question will be his horizontal projection.

Plate 16. Conic Sections I.

Prob. 1. Triangular Section. Cutting plane passes through vertex and intersects P_1 1″ to left of axis.

Prob. 2. Elliptical Section. Cutting plane inclined to P_1 at 45°, intersects P_1 2″ to left of axis.

Cone 3″ base, 3½″ high.

Three views and development.

To obtain the plan in Prob. 2, we pass a number of auxiliary planes, for instance, plane I which appears as circle I in plan and gives us two points a of the ellipse in plan.

Another method for obtaining points for the curve consists of drawing a number of elements, for instance, "I," and find where they intersect the cutting plane. To this end the base circle may be conveniently divided into a number of equal parts.

In order to find the development of the cone, Prob. 2, the true length of each element, for instance, 1—a must be determined. Its true length appears on the side element of the cone as 1^1—a^1.

The development of the top must be the true sectional area, which is found by the method given on Plate 15 Probs. 3 and 4.

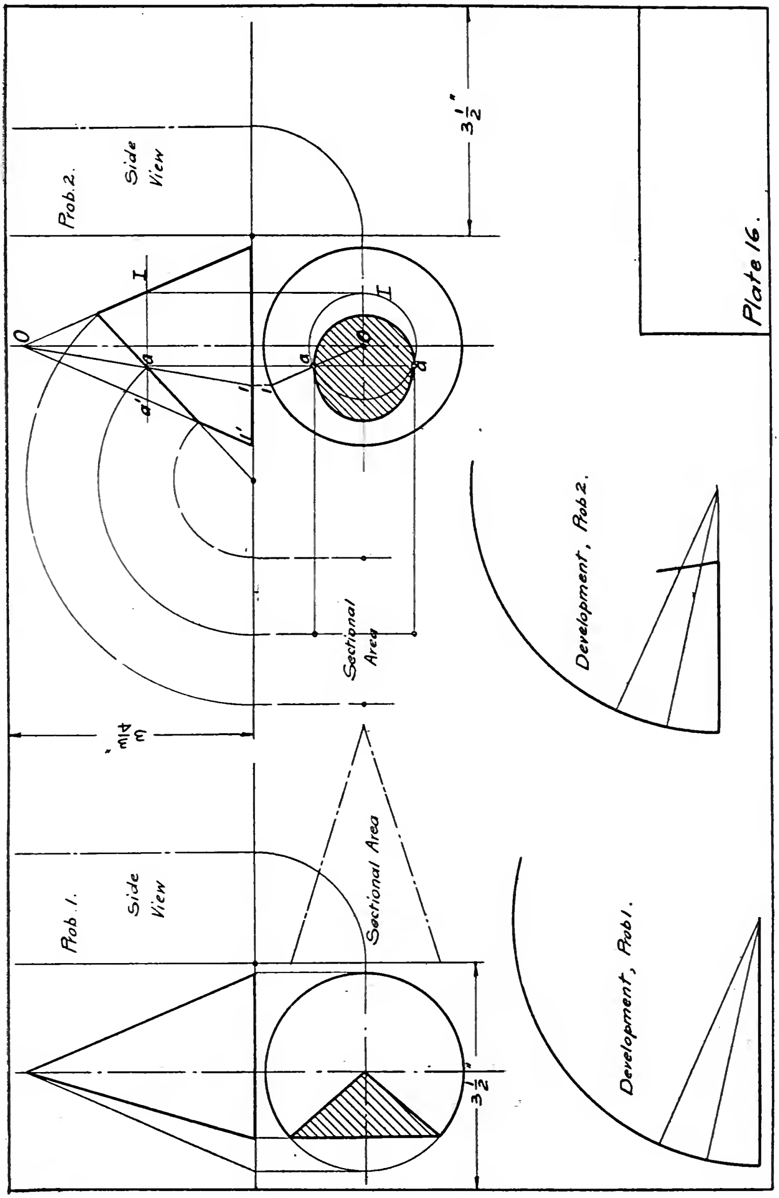


Plate 16.
Prob. 2.
Side View
Sectional Area
Development, Prob. 2.
Prob. 1.
Side View
Sectional Area
Development, Prob. 1.
3 1/2"
3 1/4"
3 1/2"

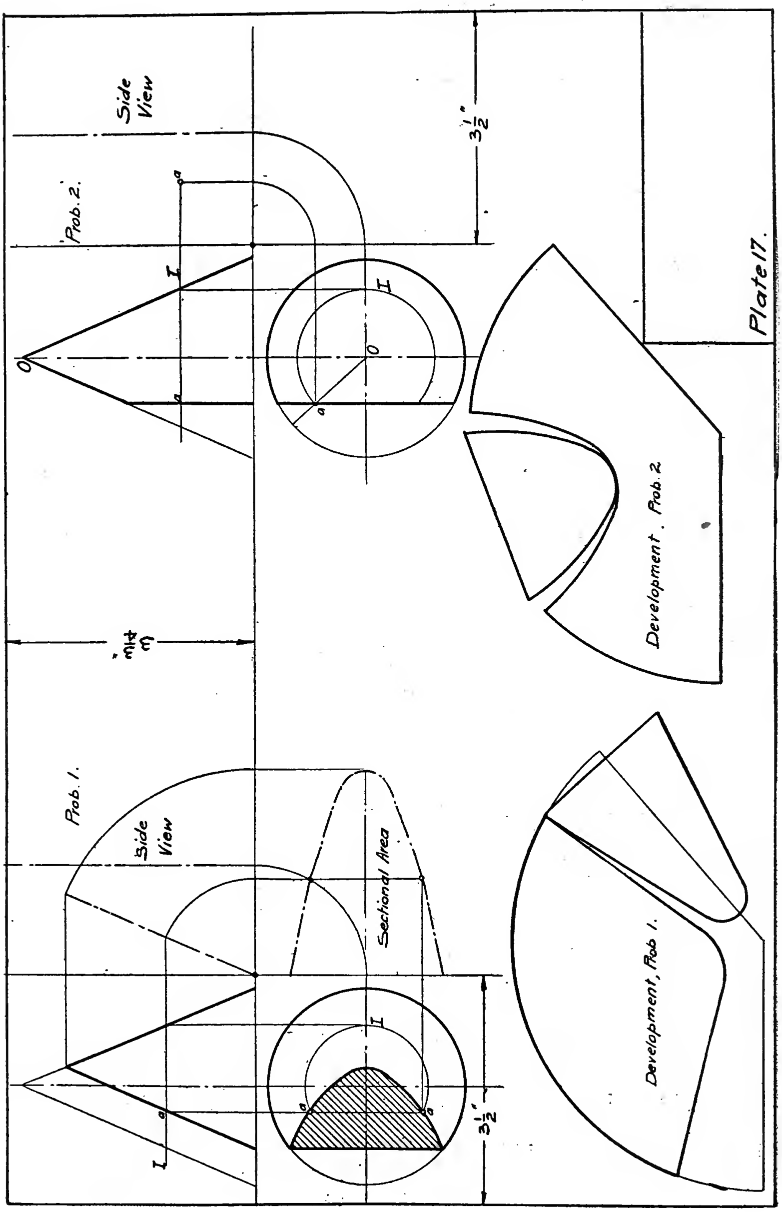

Side View
Prob. 2.
3½"
Plate 17.
Development. Prob. 2
Prob. 1.
Side View
Sectional Area
3½"
Development, Prob 1.

Plate 17. Conic Sections II.

Prob. 1. Parabolic Section. Cutting plane parallel to one element, intersects P_1 1″ to left of axis.

Prob. 2. Hyperbolic Section. Cutting plane parallel to and 5/8″ to left of axis.

Cone 3″ base, 3½″ high.

Three views and development.

To find curves of intersection, pass auxiliary cutting planes, for instance, I, which will furnish points a.

The developments are found by dividing the base circle into any number of parts and determining the true length of each element.

Spheric Sections.

All spheric sections are circles and if the sections are parallel to P_1 they appear as such in the plan. Therefore, to find the projection of a point located on the sphere, pass a cutting plane through the point, as shown in the elevation, and draw the horizontal projection of the cutting plane, which is a circle. In Fig. 18 a number of points given in one view are to be found in the other projection. For instance, find the horizontal projection of point 2, having given its projection, in the elevation. Draw cutting plane II parallel to the horizontal which will give circle II in the plan. The horizontal projection of point 2 is at the intersection of circle II and a line dropped from the vertical projection of point 2.

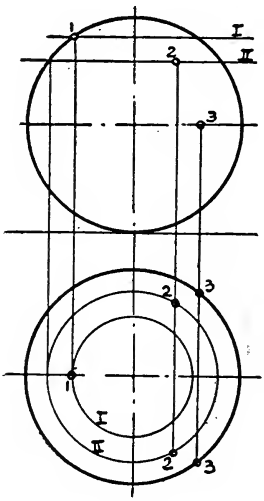


FIG. 18.

Plate 18. Spheric Sections.

Prob. 1. Cutting plane perpendicular to P_2 and inclined at 45° to P_1, intersects P_1 1⅛″ to left of axis.

Prob. 2. Cutting plane perpendicular to P_1 and inclined at 45° to P_2, intersects P_2 1⅝″ to left of axis.

Prob. 3. Development of sphere, method 1.

Prob. 4. Development of sphere, method 2.

Diameter of sphere 2″.

In Probs. 1 and 2 the sections being inclined, the projection of the section is an ellipse, the points of which are found by means of horizontal cutting planes. The construction of the sectional area proves these apparently elliptical sections to be circles.

Probs. 3 and 4 give two approximate developments of a sphere. In Prob. 3 the circumference is divided into a number of equal parts, which are joined by straight lines, thus transforming the circular section of the sphere into a polygon. Then these lines are produced until they intersect the center line and with these lines as radii the development of a cone is drawn, from which a development generated with the next smaller radius is deducted, leaving a narrow circular strip, representing the development of part of the sphere. This process is repeated for the rest of the sphere as indicated in the illustration.

In Prob. 4 the sphere is cut like an orange into slices, and the surface of each slice is developed separately. The length of such a slice must equal half the circumference of the sphere. The curves of the strips are drawn by circular arcs, or, they may be constructed by finding their width at different points from the plan.

Plate 19. Sections of Various Solids.

Prob. 1. Machine nut for 4″ bolt.

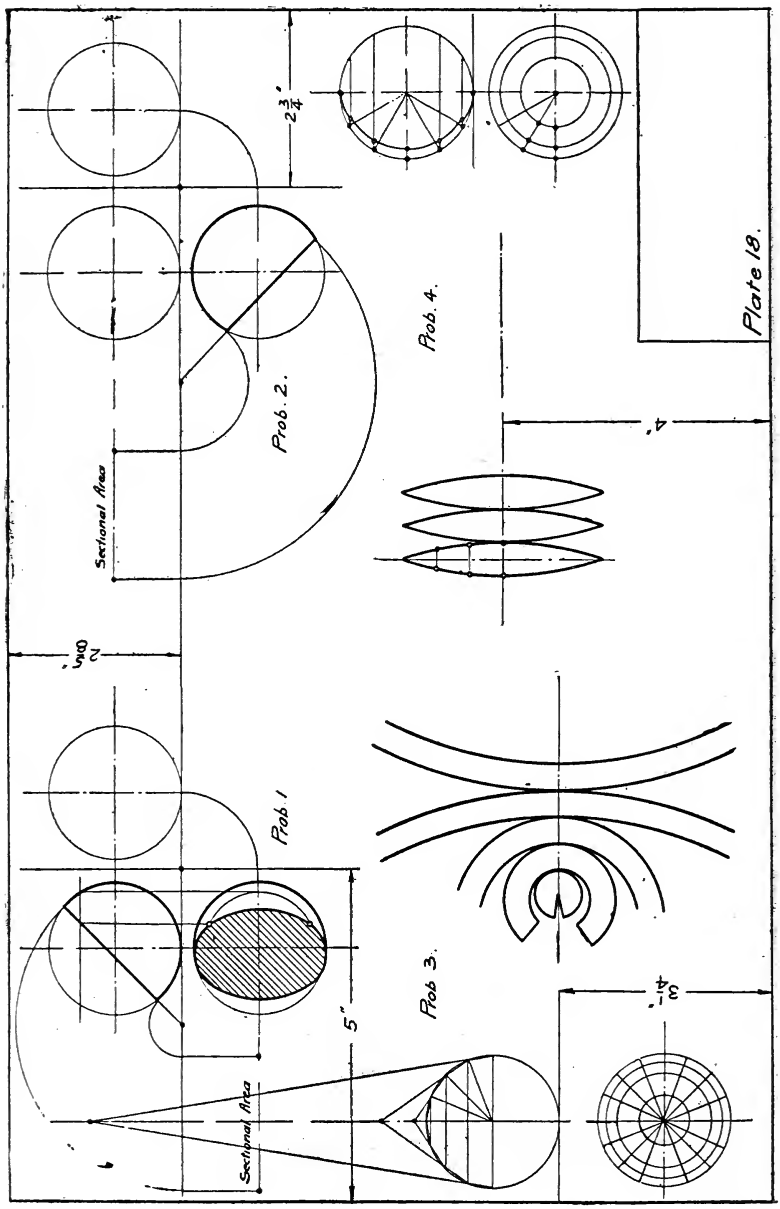


Plate 18.
Prob. 1
Prob. 2.
Prob. 3.
Prob. 4.
Sectional Area
Sectional Area
2¾"
5"
4"
3¼"

Prob. 2. Connecting rod stub ends.

The solids represented here are or have been originally *solids of revolution.* A surface of revolution is generated by the revolution of a straight or curved line about an axis. Cones, cylinders, and spheres are examples of solids of revolution.

In Prob. 1 the machine nut was generated from a double (resp. single) cone, by passing through the cones six vertical and two (resp. one) horizontal cutting planes, Fig. 19. The six vertical cutting planes are so placed as to form a regular hexagon when shown in plan and each of them, by its intersection with the surface of the cones, forms a curve which is an hyperbola. The elements of the cones form an angle of from 30° to 60° with the horizontal.

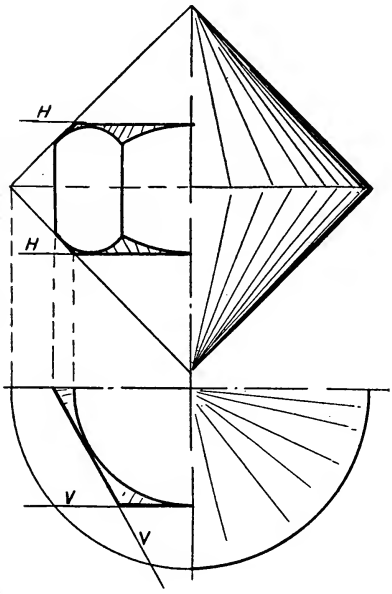
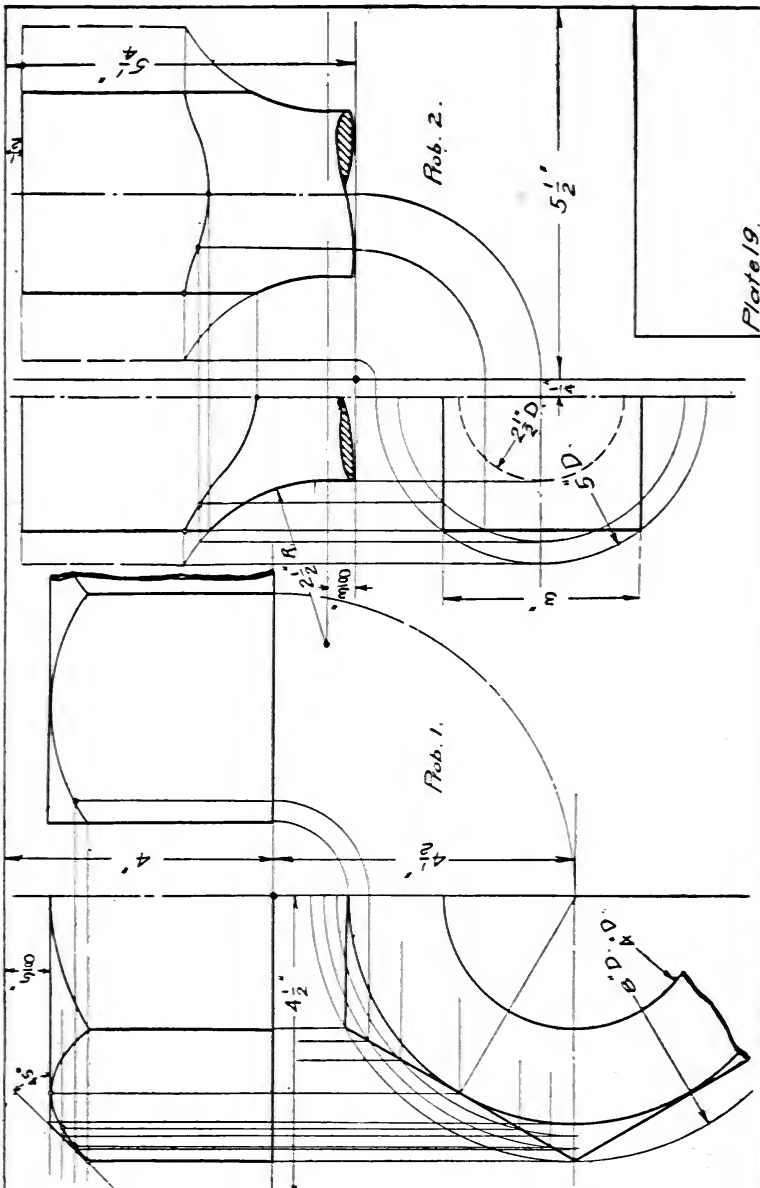


Fig. 19.

To construct the curves pass a number of (equally) spaced horizontal cutting planes through the cones and vertical cutting planes. These will give a number of concentric circles in the plan of (regularly) varying diameters. The points of intersection of these circles with the sides of the hexagon, projected upon their respective cutting planes in the elevation, give points for the curves of the nut.


Prob. 2.
Prob. 1.
Plate 19.

Prob. 2 represents the stub end of a connecting rod, Fig. 20. It is cut from a solid of revolution, consisting of two superimposed cylinders of different diameters joined by another solid of revolution, by 4 vertical cutting planes which form a rectangular horizontal cross-section having its center coincident with that of the cylinders. The curve of intersection formed by the planes cutting the surface of revolution is found by means of cutting planes.

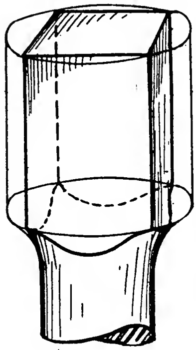


Fig. 20.

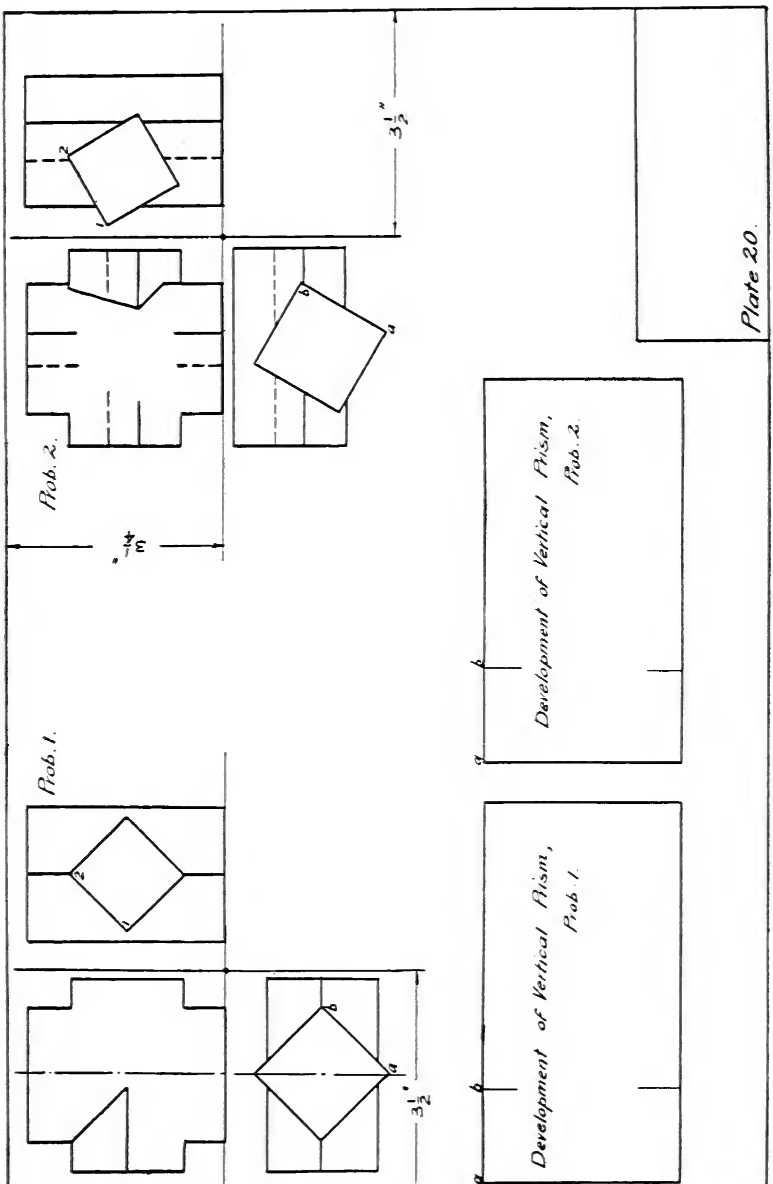


Plate 20.
Prob. 2.
Prob. 1.
3 1/2"
3 1/4"
3 1/2"
Development of Vertical Prism, Prob. 2.
Development of Vertical Prism, Prob. 1.
a
b

INTERSECTIONS.

C—Intersections.

By "intersections" we mean the penetration of one solid into another. Where they meet we have the line of intersection, which must be geometrically located before we can make the developments.

Plate 20. Intersection of Prisms I.

Prob. 1. Horizontal prism 1¼ x 1¼, 3″ long. Faces inclined at 45° to P_1 and P_2.

Vertical prism 1½ x 1½, 3″ high, faces inclined at 45° to P_2.

Prob. 2. Vertical prism 1⅜ x 1⅜, 3″ high. Nearest edge to P_2 ½″ away from P_2. Left face nearest P_2, making an angle of 60° with P_2.

Horizontal prism 1¼ x 1¼, 3″ long. Nearest edge to P_2 ⅛″ away from P_2. Lower face nearest P_2, making an angle of 30° with P_2.

Three views and developments of vertical prisms.

Plate 21. Intersections of Prisms II.

Prob. 1. Vertical prism 1⅜ x 1⅜, 3″ high. Nearest edge to P_2 ¼″ away from P_2. Left face nearest P_2 making an angle of 30° with P_2.

Inclined prism 1¼ x 1¼, 3⅛″ long, parallel to P_2, making an angle of 20° with P_1. Nearest edge to P_2 ½″ away from P_2. Lower face nearest P_2 making an angle of 60° with P_2.

Prob. 2. Horizontal irregular quadrilateral prism, 3″ long. Vertical irregular pentagonal prism, 3″ long. Assume rest of dimensions.

Three views and developments of vertical prisms.

Plate 22. Locomotive Steam Boiler.

Show correct developments of boiler sheet A-B-C, dome and slope sheet.

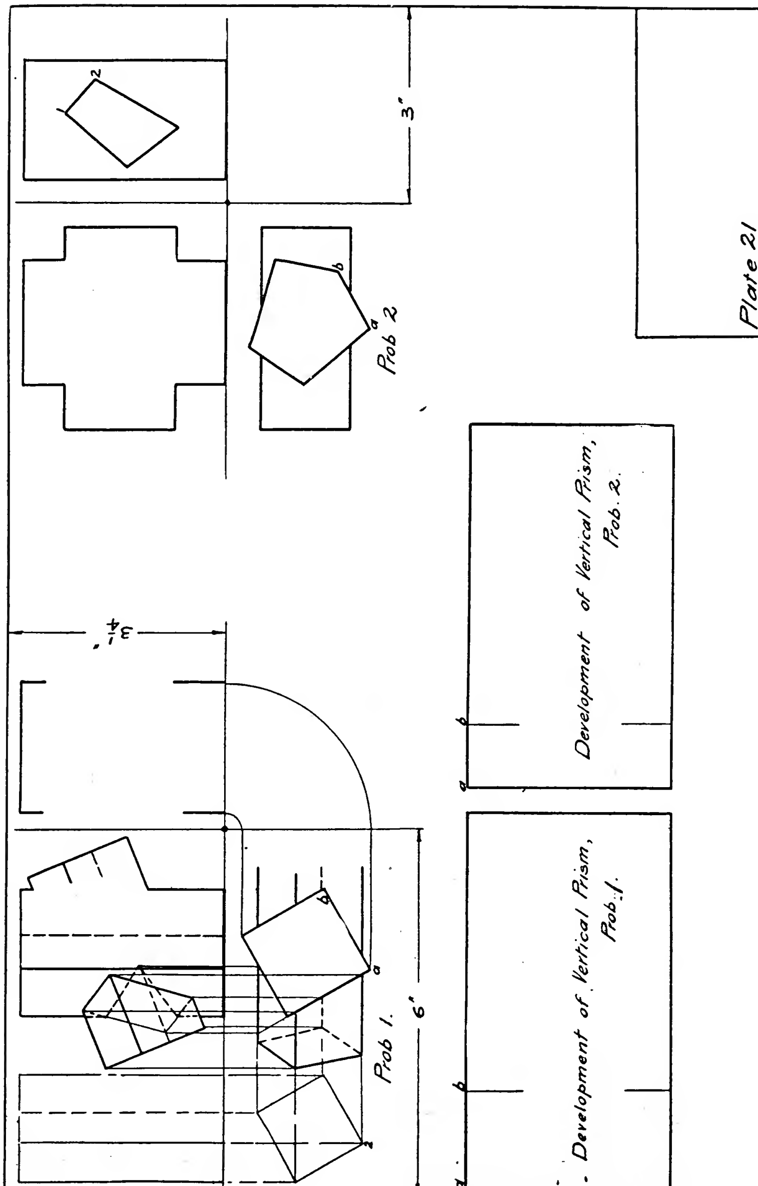


Plate 21
Prob 2
Prob 1.
Development of Vertical Prism, Prob. 2.
Development of Vertical Prism, Prob. 1.
3"
6"
3 1/4"

First construct curve of intersection of dome and boiler by showing the elements of the dome in both views and projecting the true length of the elements in the end view upon the front view. The development of the dome is thus easily found.

In sheet A-B-C construct carefully the cut-out for the dome. Before developing the slope sheet, determine the sectional area of a plane passed at right angles to the sloping line, which will prove to be a semi-ellipse. The development of the slope sheet then consists of the development of an oblique prism of semi-elliptical cross-section, to which are added the two triangles a m n.

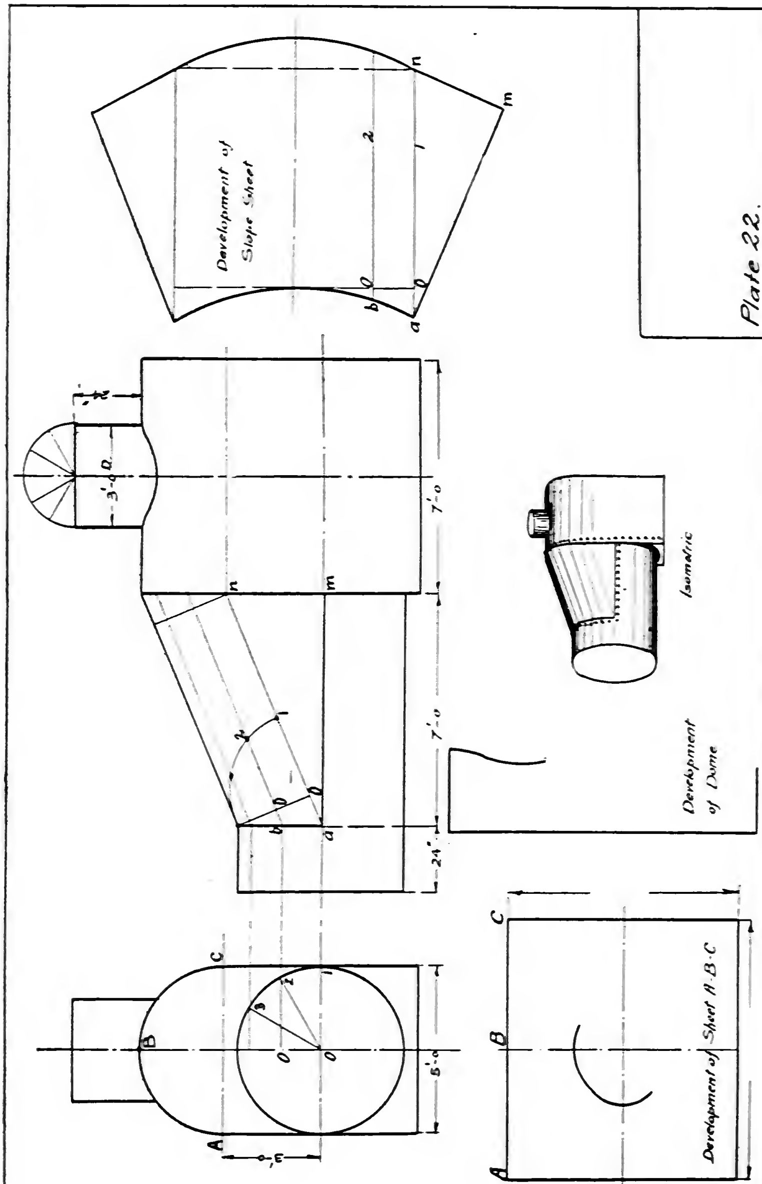

Development of Slope Sheet
Plate 22.
Isometric
Development of Dome
Development of Sheet A·B·C
7'-0
7'-0
24'
8'-0
3'-0 D.

Plate 23. Intersections of Cylinders.

Prob. 1. Flanged Y-branch. Main pipe 2¾" high, outside diameter 2¼". Branch pipe 2⅝" long from intersection, outside diameter 1⅜". Angle between centres of pipes 60°. Offset of centres of pipes ¼". Thickness of pipes ⅛".

Prob. 2. Inclined cross (half section). Outside diameter of pipes 1⅞". Thickness of pipes = ⅛". Inclined cylinder makes an angle of 45° with P_2 and an angle of 15° with P_1.

Show three views of each problem and developments as indicated on plate.

In Prob. 1 the axes of the two cylinders are on different but parallel planes. First draw the cylinders in elevation, neglecting the curve of intersection. Then determine the plan view, drawing auxiliary circles on the center line of the inclined cylinder, by the use of which the horizontal projection of the flange may be obtained. The curve of intersection in the elevation is found from the plan.

In Prob. 2 the inclined cylinder is shown inclined to both planes similar to position *c* of Prob. 3 on Plate 13. This is made possible by drawing an auxiliary projection, showing the inclined cylinder in position *b*.

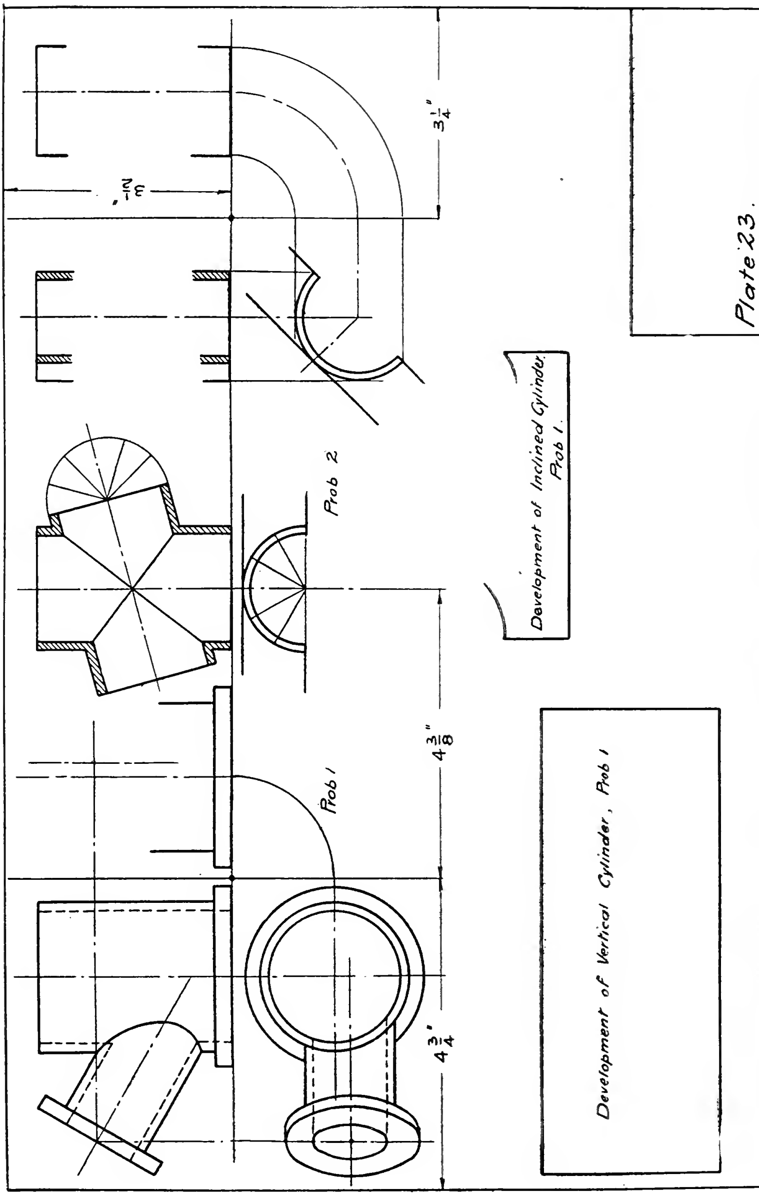


Plate 23.
Development of Inclined Cylinder. Prob 1.
Development of Vertical Cylinder, Prob 1
Prob 2
Prob 1
3 1/4"
4 3/8"
4 3/4"

Plate 24. Intersections of Spheres.

Prob. 1. Sphere and Pentagonal Pyramid. Sphere $2\frac{7}{8}''$ diameter. Dimensions of irregular pentagonal pyramid may be assumed.

The problem of finding the curves of intersection is one of finding the intersections of a number of vertical cutting planes with the surface of the sphere. These intersections are portions of circles, which appear as parts of ellipses, where the cutting planes are inclined to P_2.

Points of intersection in the elevation are found by passing through the solids a number of auxiliary planes parallel to P_2.

The circular cut-outs in the development of the prism correspond to the circles which are found by the intersection of the vertical planes of the prism and the surface of the sphere.

Prob. 2. Sphere and cylinder. Hemisphere $3\frac{1}{4}''$ diameter, resting on P_1. Cylinder $2''$ diameter. Axes of both solids on plane parallel P_2, $\frac{3}{8}''$ apart.

Determine the nature of the curve of intersection by the use of cutting planes.

Prob. 3. Sphere and cone.

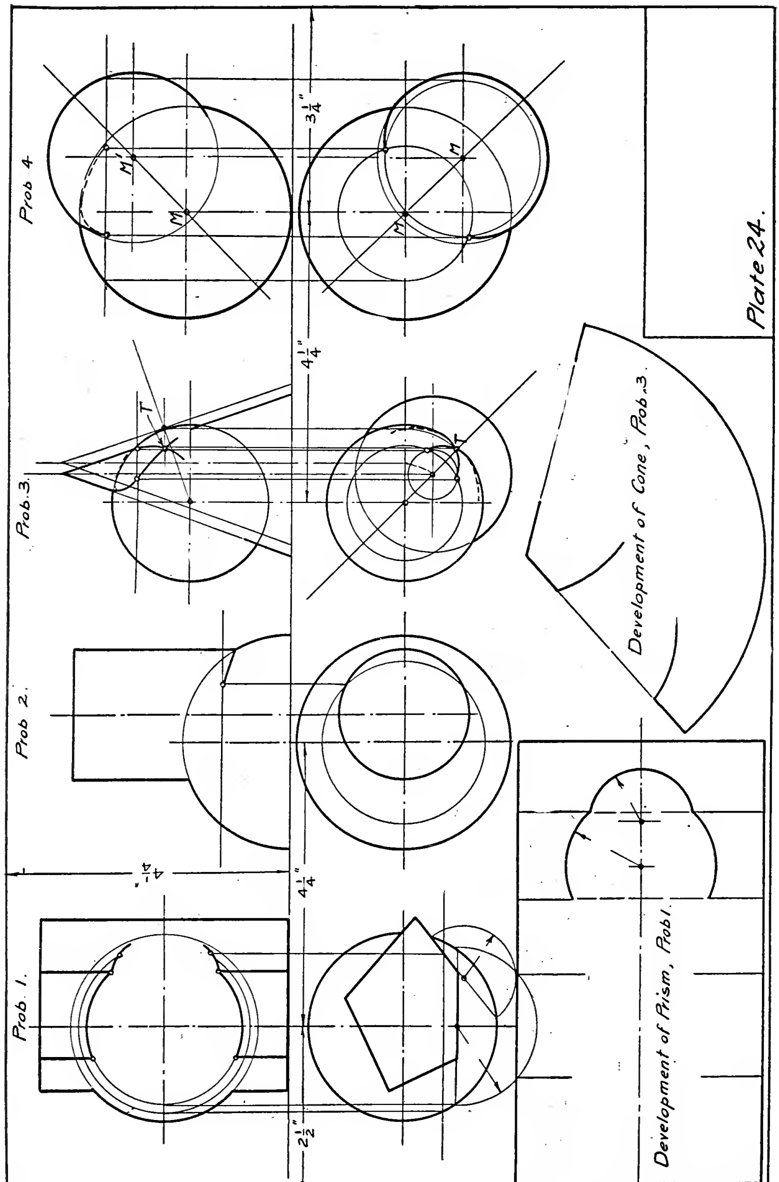
Cone resting upon P_1, height $= 3\frac{1}{2}''$, diameter of base $= 2\frac{1}{2}''$. Center $2\frac{1}{8}''$ from P_2.

Diameter of sphere $= 2\frac{3}{8}''$.

Sphere to be placed within cone so that its surface is tangent to that of the cone. Plane passing through axes of sphere and cone to be perpendicular to P_1, making an angle of 45° with P_2. Show development of cone.

There are 3 possibilities of intersection of a sphere and a cone, Fig. 21.

a. Some of the elements of the cone do not intersect the surface of the sphere.



Prob. 1.
Prob 2.
Prob. 3.
Prob 4
M
M'
T
4¼"
3¼"
2½"
Development of Cone, Prob. 3.
Development of Prism, Prob 1.
Plate 24.

b. All of the elements of the cone intersect the surface of the sphere.

c. One element of the cone does not intersect the surface of the sphere.

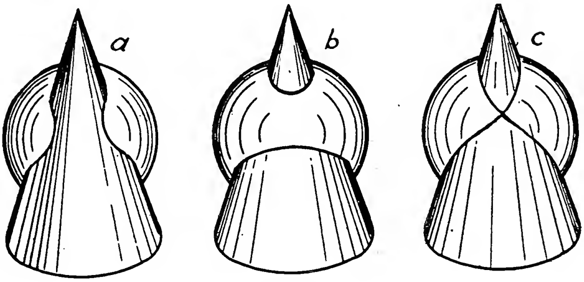


FIG. 21.

Prob. 3 illustrates case *c*. The point of tangency T is found by an auxiliary projection, where the plane passing through the axes of both the cone and the sphere is parallel to P_2 (see position *b* on plates 13 and 14.)

Draw the required plan and elevation in the same way as the plan and elevation in position *c* is obtained from position *b* on plates 13 and 14.

Points for the curves are found by means of cutting planes.

Having developed the surface of the plain cone, points for the curves of intersection are found by laying off from the vertex of the development along each element, the distances from the vertex (obtained from the elevation) to the points of intersection of that element with the surface of the sphere.

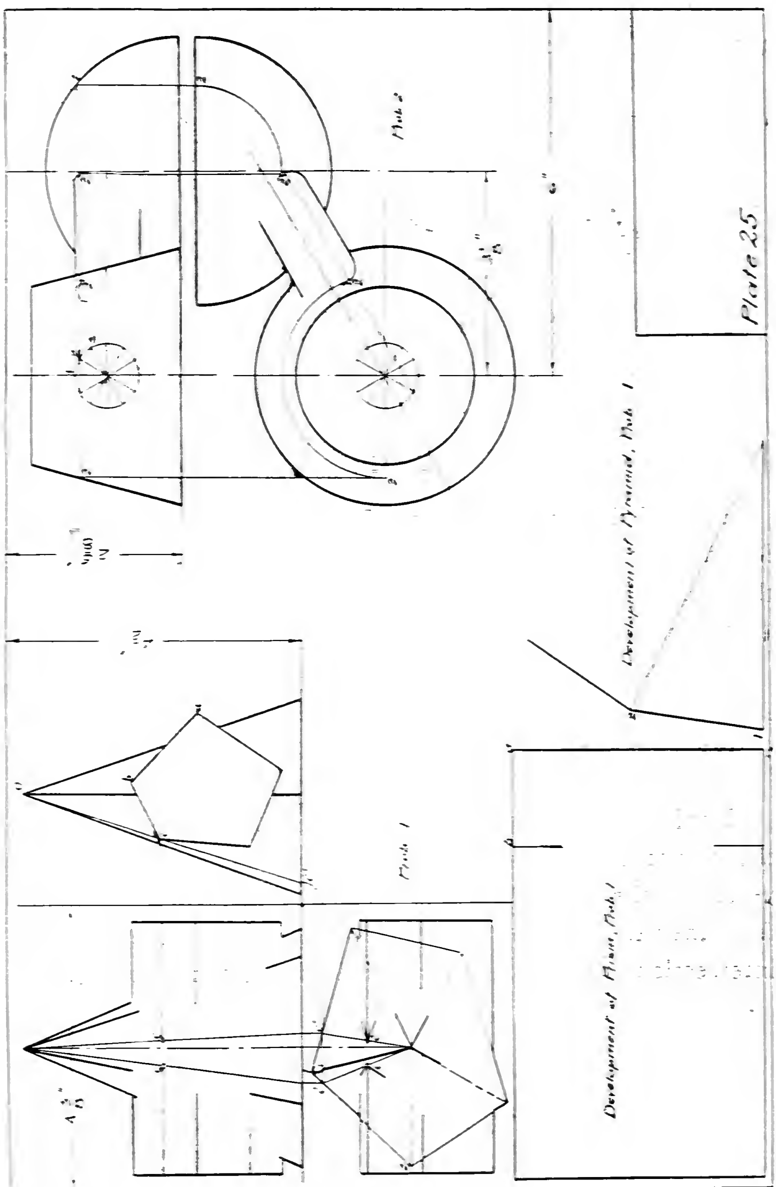


Plate 25

Prob. 4. Two Spheres. Their common axis inclined to both planes at 45° in projection. Diameter of spheres = 3½″ and 2⅝″. Distance between centres in projection = 1⅛″. Obtain limiting points of curves. Find true distance from M to M^1 by a position b (see plates 13 and 14.) Curve of intersection to be found by means of auxiliary cutting planes.

Plate 25. Intersection of Prisms with Pyramids.

Prob. 1. Prism with pyramid.

Irregular pentagonal pyramid 4¼″ high, base in P_1, vertex 1⅝″ from P_2.

Irregular horizontal pentagonal prism, 3¾″ long, base inscribed in a circle 2¼″ diameter; centre 1⅜″ above P_1 and 1⅞″ from P_2. Prism and pyramid to be constructed so that one edge of each solid remains unintersected. Draw the plan in each case (2 polygons) and obtain the two other views by projection. To find the terminating points of the sides of the prism in plan, draw elements from the vertex of the pyramid through each of the edges of the prism, b, c, d, e, and show the horizontal projections of these elements intersecting the edges of the prism in the required points. Make development of both solids.

Prob. 2. Cone with cylinder and sphere.

Frustrum of cone, 4″ base diameter, 2¾″ top diameter, 2¼″ high, resting on P_1, its centre 3⅛″ away from P_2.

Semi-sphere 4⅛″ diameter, centre on P_1, ⅛″ away from P_2. Horizontal cylinder, 1″ diameter, inclined as 30° to P_2, its axis ⅛″ above P_2.

Plate 26. Intersection of Cone with Oblique Prism.

Height of cone 4½″, diameter of base 4″; cone rests on P_1 with centre line 3″ from P_2.

Base of oblique prism is an irregular pentagon, dimensions to be taken from plate. Projections of edges of prism on P_2

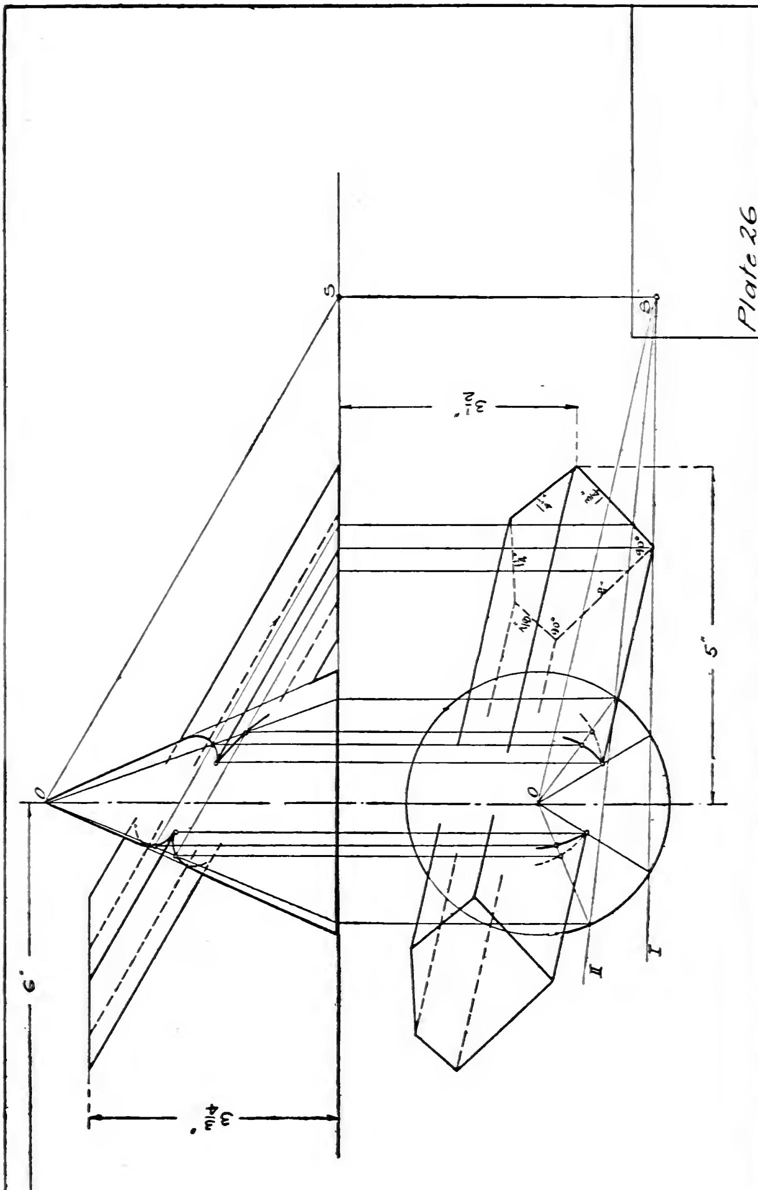


Plate 26
$3\frac{1}{2}$"
5"
6"
$3\frac{1}{4}$"
S
O
I
II

make an angle of 30° with P_1. Projections of edges on P_1 make an angle of 15° with P_2. (What is the true angle of inclination?)

Points of the intersecting curves may be found by drawing horizontal cutting planes or by passing auxiliary planes through the vertex of the cone and an outside point S, which lies in P_1 at its intersection with line O-S parallel to the edges of the prism.

Both methods may be employed in this problem and the results verified.

Plate 27. Intersection of Cone with Pyramid.

Cone 2½" diameter, 6⅜" high.

Pyramid, 4¾" high, base as per dimensions.

This problem is solved in a similar way by the use of cutting planes which pass through the vertex of both pyramid and cone.

D—Solids with Warped Surfaces.

A warped surface cannot be developed by any of the methods previously referred to. It may be constructed approximately by the *"Method of Triangulation."* The construction is as follows: Lay off on the projections of the solid, small triangles at regular intervals, determine their true size and place them adjacent to each other. The base of each triangle is shown in the plan, the altitude in the elevation. Any warped surface may be developed in this manner.

Plate 28. Development of Bath Tub.

In constructing the development, we assume the tub being made in four pieces—A, A, B and C—the separating seams shown in plan at 1-2 and 0-9.

The lower end of the tub forms part of a cone and should present no difficulty to develop.

For the upper end the development will be obtained by

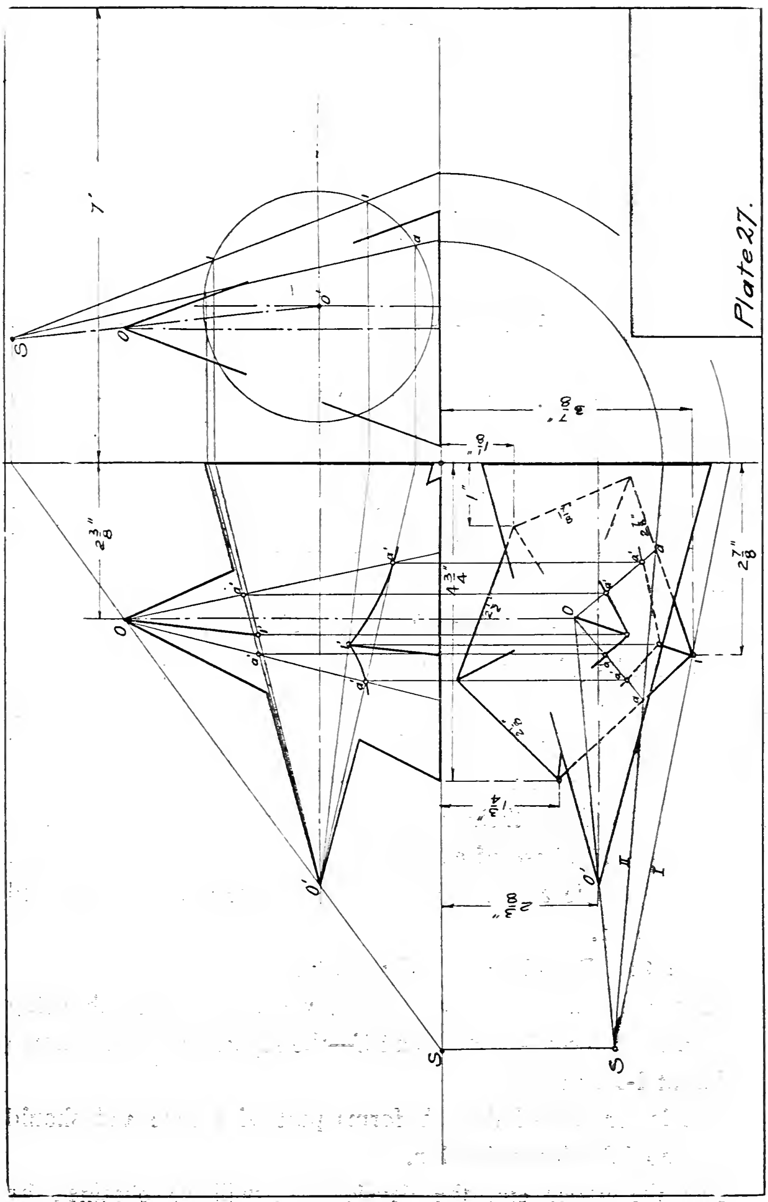
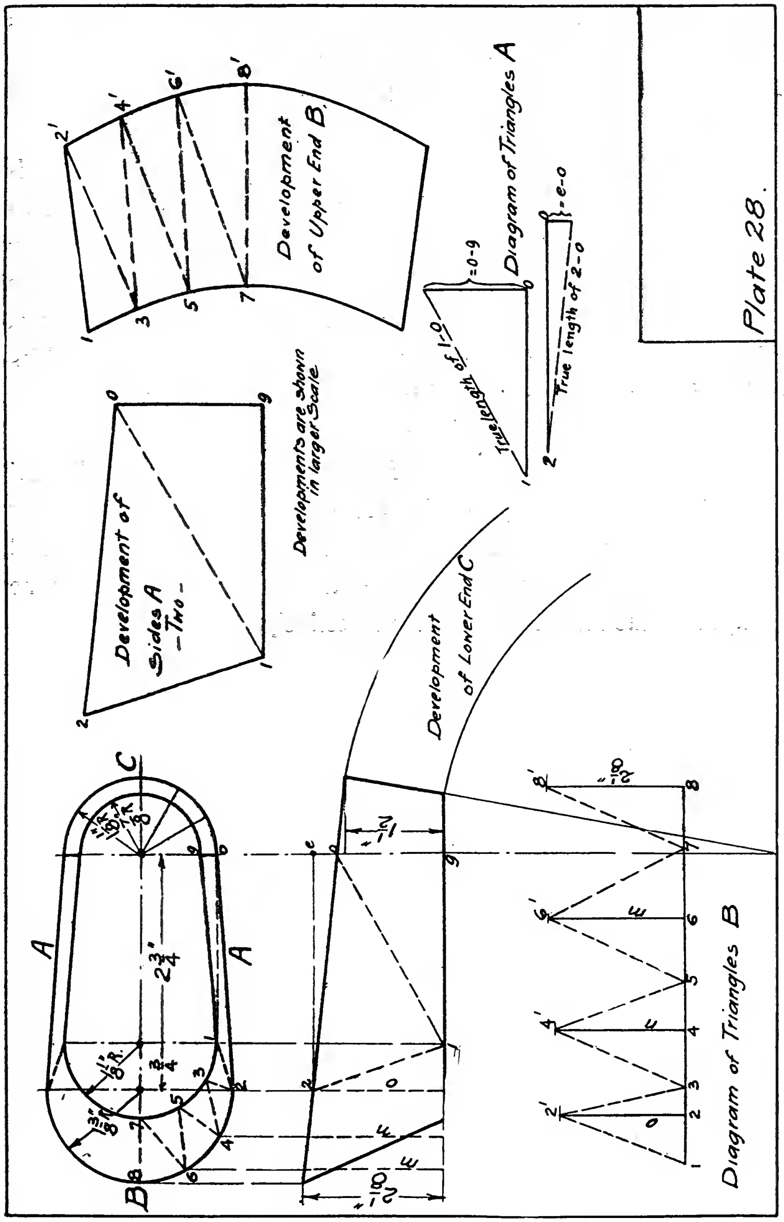


Plate 27.


Development of Upper End B.
Diagram of Triangles A
True length of 1-0
=0-9
True length of 2-0
=e-o
Development of Sides A
— Two —
Developments are shown in larger Scale
Development of Lower End C
Diagram of Triangles B
Plate 28.

triangulation. First obtain diagrams of triangles as follows: Divide both quarter circles at upper ends in plan into equal spaces and connect by lines 1-2, 2-3, etc. From the points 2, 4, 6 and 8 drop lines to the elevation.

Then the dotted lines in plan represent the bases of the triangles, whose altitudes are equal to the various heights in elevation. For example, the true length of the line 6-7 in plan may now be taken from the line 6^1-7 in the diagram of triangles. The development then consists of a number of triangles put together, the base of each being taken from the plan and the two sides taken from the dotted line of the Diagram of Triangles.

The sides A are also developed by triangulation.

First draw the Diagram of Triangles A. The horizontal lines 1-0 and 2-0, respectively, are equal to the corresponding lengths in plan. The vertical lines are equal to the lines 0-9 and e-o measured in elevation. The dotted diagonals are the true lengths of the lines 1-0 and 2-0, respectively.

CHAPTER IV.

PERSPECTIVE DRAWING.

Perspective is the art of representing objects as they appear to the eye at a *definite* distance from the object. In orthographic (perpendicular) projection the views represent the object as

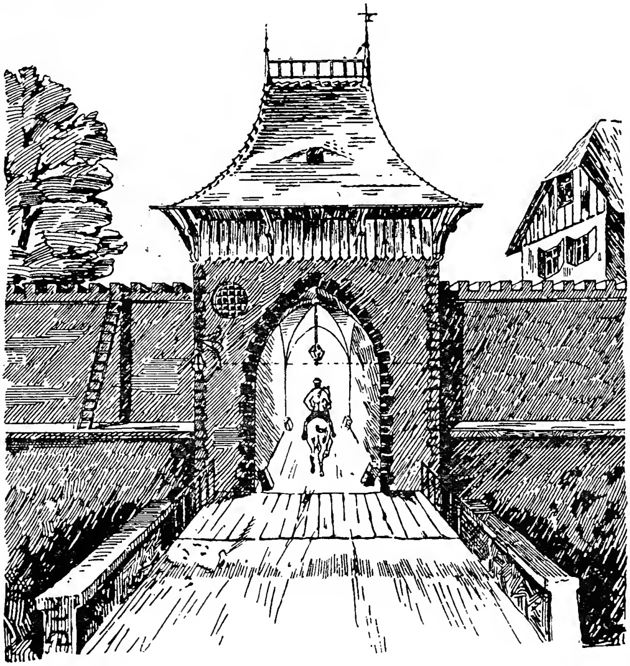


Fig. 22.

seen when the eye is *infinitely* distant. By the perspective method then the lines drawn from points on the object to the eye converge and intersect at the point of sight.

Before beginning the study of perspective projection let us observe some of nature's phenomena of perspective. These phenomena become more apparent when we attempt to sketch from nature. We notice that the size of an object diminishes

as the distance between the object and the eye increases. If several objects of the same size are situated at different distances from the eye, the nearest one appears to be the largest and the

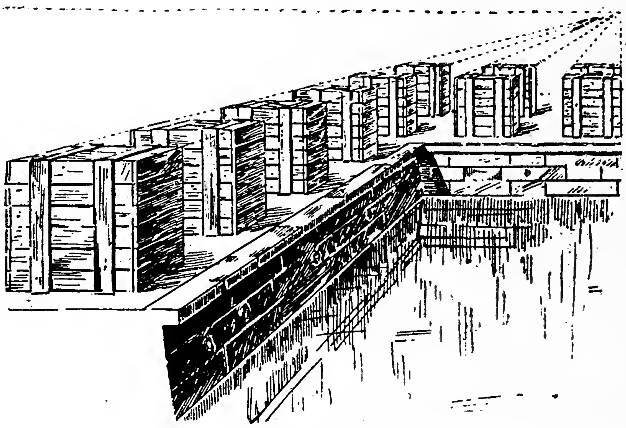


FIG. 23.

others appear to be smaller as they are further and further away.

At last the distance between the lines becomes zero and the lines appear to meet in a single point. This point is called the *vanishing point* of the lines. See Figs. 22, 23 and 24. By closer investigation of a drawing sketched from nature we find:

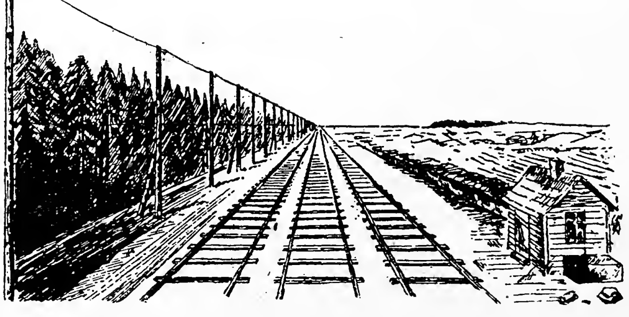


FIG. 24.

(1) The limit of our visional observation is a horizontal line, situated at the height of our eye, called *Horizon.*

(2) Objects of equal size appear smaller with increasing distance.

(3) Parallel lines converge into one point, called *vanishing point.* For horizontal lines this point is situated at the height of the eye, that is, it lies in the horizon.

(4) Vertical lines appear vertical.

(5) The location of the observer's eye is called the *point of sight* and is located in the horizon.

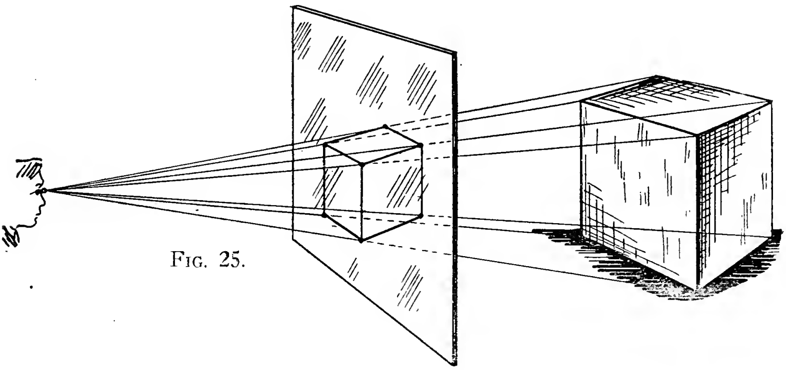


FIG. 25.

When an object in space is being viewed rays of light, called *visual rays,* are reflected from all points of its visible surface to the eye of the observers.

If a transparent plane, Fig. 25, be placed between the object and the eye the intersection of the visual rays will be a projection of the object upon the plane. Such projection is called the *perspective projection* of the object. The plane on which the projection is made is called the *picture plane.* The position of the observer's eye is the *point of sight.*

This principle is illustrated by models where red strings represent the rays, piercing a glass plate.

A—Perspective by Means of Plan and Elevation.

Above can be put to practical use if we obtain a perspective projection in plan and elevation and then proceed by orthographic projection to obtain the perspective.

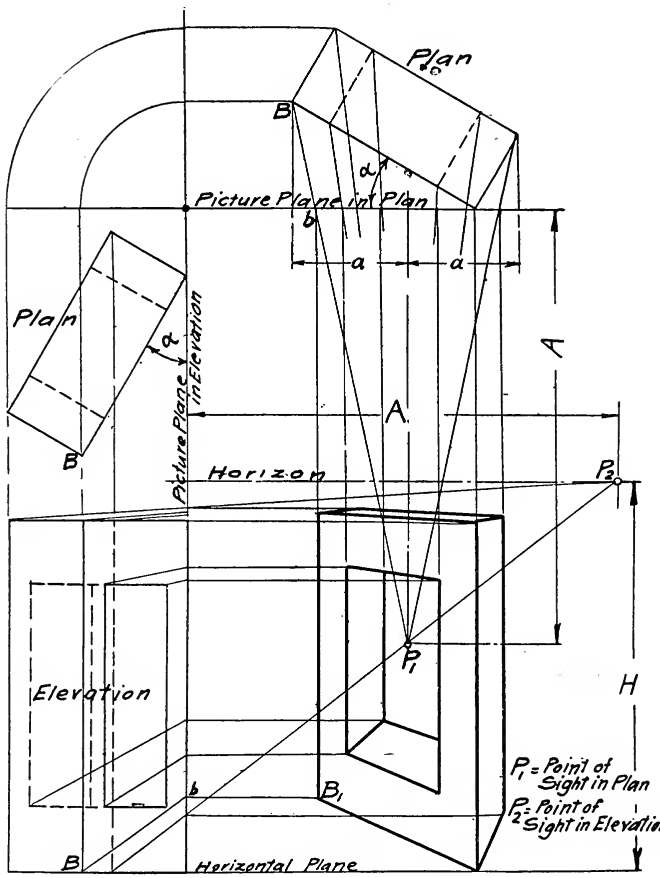


Fig. 26.

In Fig. 26 plan and elevation of a prism, such as is used on Plate 1, is shown, its front face making an angle with the picture plane. As a general rule, the object is placed behind the picture

plane with one of its principal vertical lines lying in the picture plane. P is the point of sight (the observer's eye). Its distance A from the picture plane in plan depends a great deal on the size of the object and it is important that the best view point is obtained.

If a house about 40′ high is to be sketched, the point of sight should be taken about 80′ from the picture plane. A good rule to follow is to make this distance about twice the greatest dimension. When large objects are to be represented the best results are obtained when the point is taken nearly in front of the object.

The distance of the horizon from the horizontal plane equals the height of the eye above ground and may be taken = 5′ — 3. For high objects this distance may be increased and for low objects decreased. In our case it is shown slightly above the object. P_1 is assumed on a vertical line half way between two lines dropped from the extreme edges of the diagram. This is not necessary, but it usually insures a more pleasing perspective projection.

To obtain the perspective of any point of the object, for instance B, draw the visual ray in both plan and elevation to P_1 and P_2, respectively. From the point of intersection b in the picture plane (in plan and elevation) project perpendicularly and thus obtain the point B_1, as perspective picture of the point B of the object. In this manner all the other points of the perspective are obtained.

This method of construction requires no further explanation and may be applied wherever plan and elevation is obtainable.

Plate. 29. Perspective of Cross.—Point of sight at a distance H=2⅜″ above floor and at a distance A=7¾″ away from object, to be placed halfway between extreme points in plan.

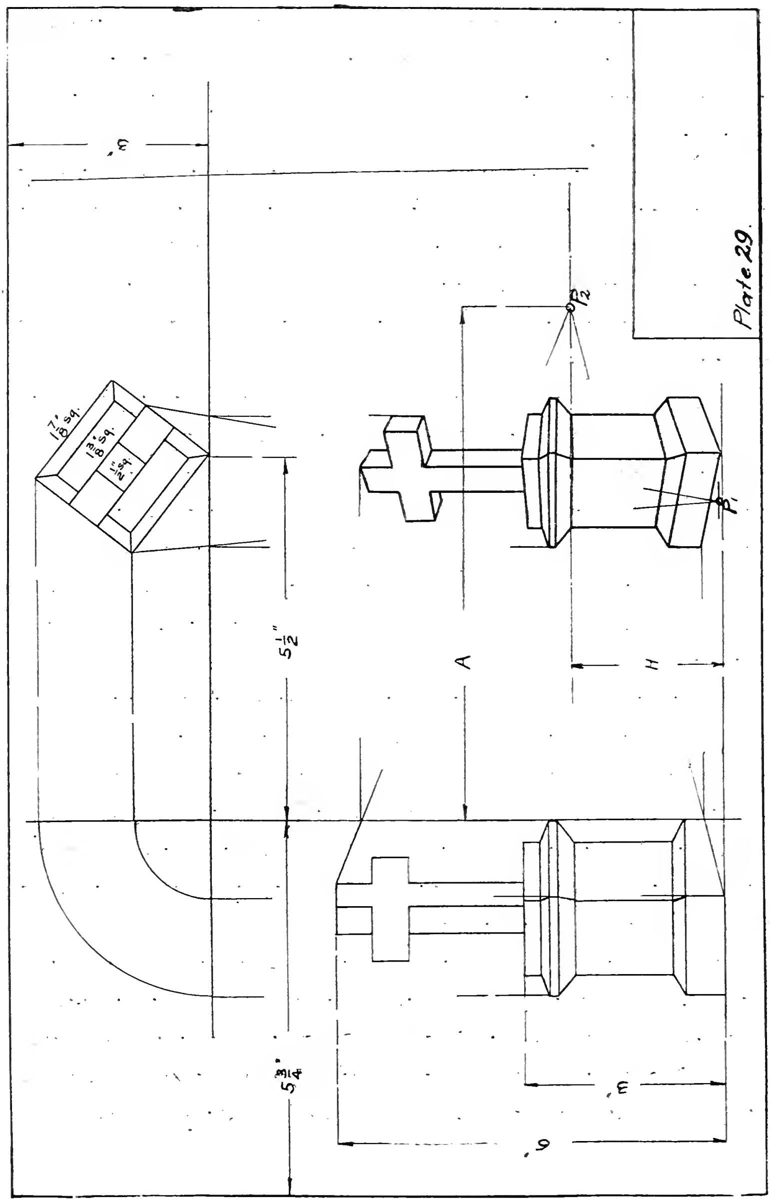


Plate 29.
3"
1 7/8" sq.
1 3/8" sq.
1/2" sq.
5 1/2"
5 3/4"
A
H
3"
6"
P_1
P_2

B—Perspective by Means of Plan and Two Vanishing Points.

Fig. 27 shows a rectangular prism in plan and elevation resting upon a horizontal plane.

The first step will be to redraw the plan, same as with the first method, behind the picture plane in plan, with the vertical

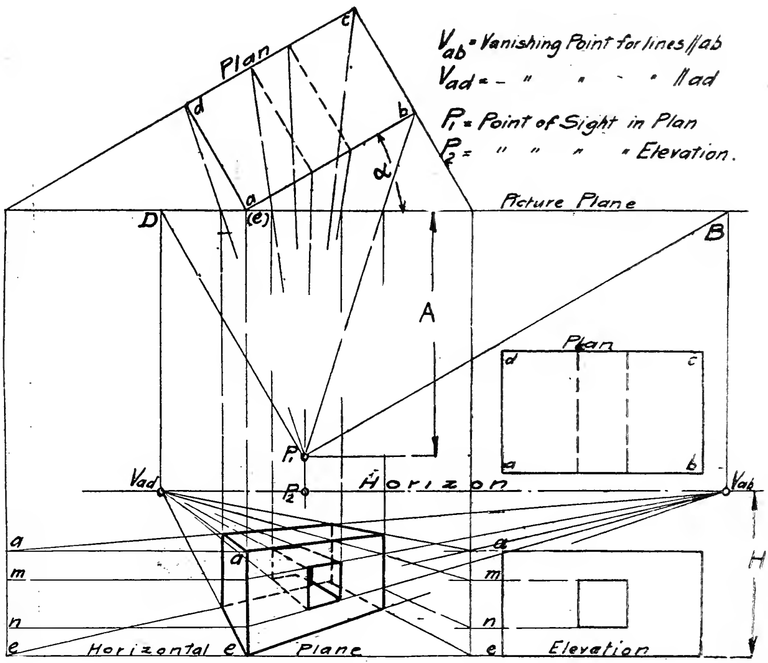


FIG. 27.

line a-e lying in the picture plane and turned so that its long side makes an angle α (30°) with the picture plane. The point of sight (P_2) is at a distance H above the floor and is located at the same height as the horizon.

Next, find the vanishing points for the different systems of lines in the object. There are three systems of lines in the prism. Vab and Vad are found by drawing lines P_1-B and P_1-D through

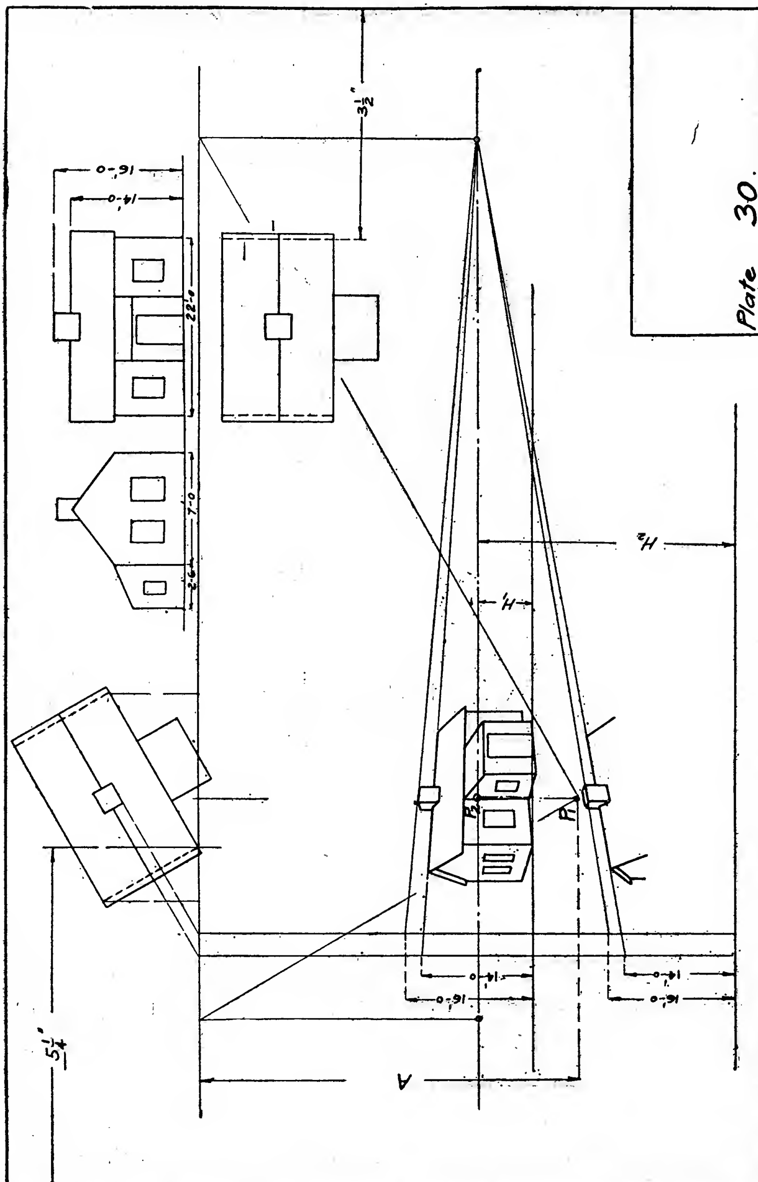


Plate 30.
3½″
16'-0
14'-0
22'-0
7'-0
2'-6
H_2
H_1
P_1
P_2
A
5¼″

P_1 parallel to a-b and a-d of the diagram and dropping vertical lines from the intersection of these lines with the picture plane (B and D) to the horizon, giving the vanishing points Vab and Vad. The third system of lines embraces the vertical lines which are drawn actually vertical and not converging towards one another.

The edge a-e of the diagram, being in the picture plane, is called the *line of measures,* as it appears in its true size in the perspective view, and from a and e in the perspective view the lines will vanish at Vab and Vad, respectively, establishing by intersection with the vertical edges all points desired.

Besides this principal line of measures other lines of measures may easily be established by extending any vertical plane in the object until it intersects the picture plane. This intersection, since it lies in the picture plane, will show in its true size and all points in it will show at their true height above the horizontal plane.

If no line in the object should lie in the picture plane there would not be any principal line of measures, and some vertical plane in the prism must be extended until it intersects the picture plane.

Instead of being some distance behind the picture plane the prism might have been wholly or partly in front of the picture plane. In any case, find the intersection with the picture plane of some vertical face of the prism. This intersection will show the true vertical height of the prism.

Plate 30. Perspective of House.—Scale $\frac{1}{8}'' = 1'$. The projections are given.

Long side of house making an angle of 30° with the picture plane. Nearest vertical edge of house to lie in the picture plane. Two perspective views of the house shall be obtained, the house being viewed from two different points. Their common distance

in Plan A = 46'. The distances H_1 and H_2 of the point of sight above the horizontal shall be 6' 6" and 31' 6", respectively. The construction of both views is exactly the same.

The fact that the porch projects in part in front of the picture plane makes no difference in the construction of the perspective projection.

C—Perspective by Means of Plan and One Vanishing Point.

In this method the plan is placed with one of its principal

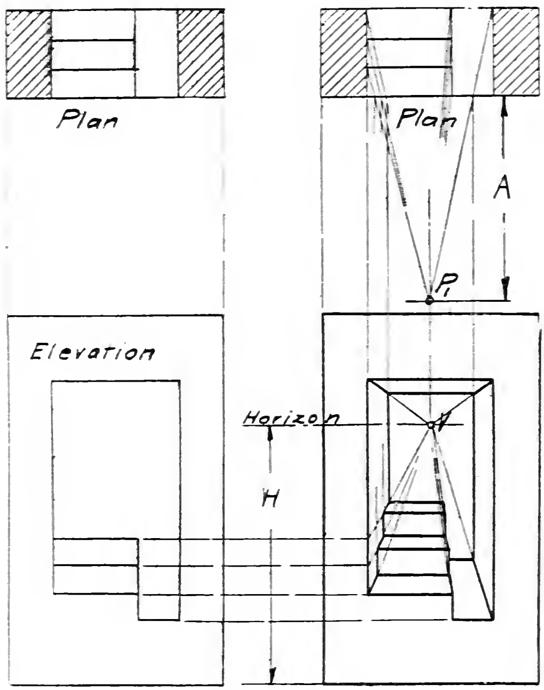


FIG. 28.

systems of horizontal lines parallel to the picture plane. This system therefore has no vanishing point, and as the vertical sys-

tem has no vanishing point, only the third system of lines will have a vanishing point.

In Fig. 28 the vertical force of the prism lies in the picture

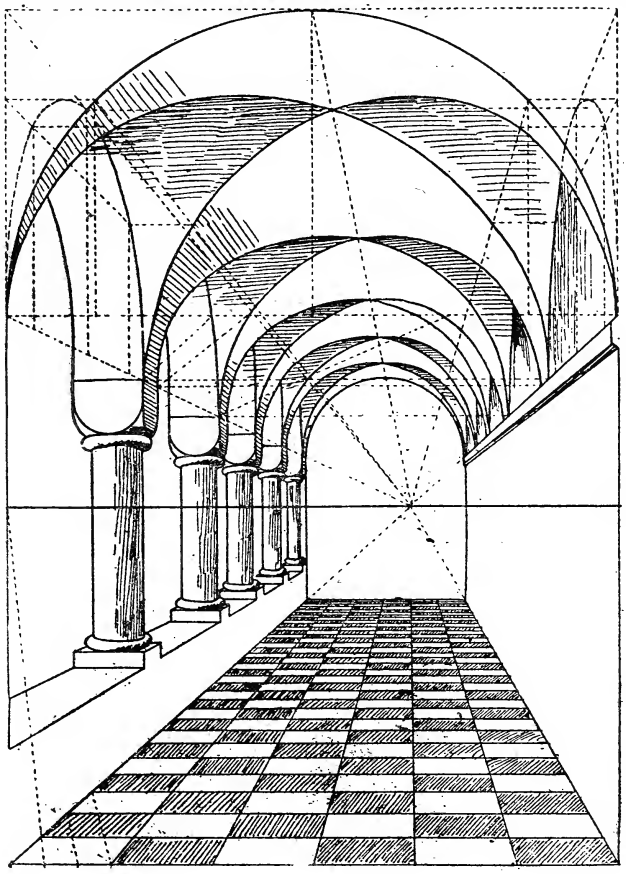


Fig. 29.

plane and shows in its true size. Its edges are lines of measures.

The construction of the perspective is easily apparent from the illustration.

Figs. 29 and 30 are problems of perspective solved by the last mentioned method.

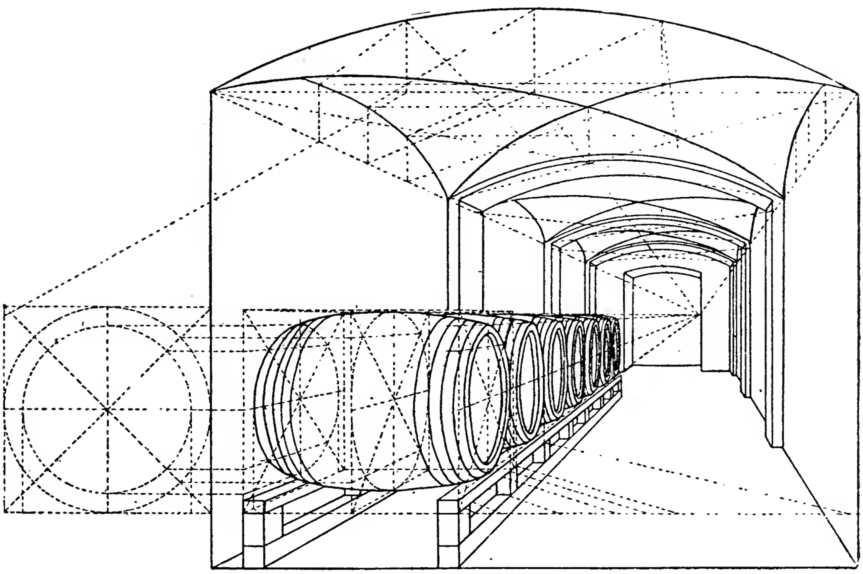


Fig. 30.

CHAPTER V.

SHADES AND SHADOWS.

The problems of finding the shades and shadows of objects are problems dealing with points, lines, surfaces and solids, the same as are dealt with in orthographic projection. The employment of shades and shadows in drawings is an aid to a more realistic representation of the object illustrated and is chiefly found in connection with architects' work.

Definitions:

1. *Shade.* When a body is subjected to rays of light, that portion which is turned away from the light is said to be in *shade.*

2. *Shadow.* When a surface is in light, and an object is placed between it and the light, that portion of the surface from which light is excluded is said to be in *shadow.*

3. *Umbra.* That portion of space from which light is excluded is called the umbra or *invisible shadow.*

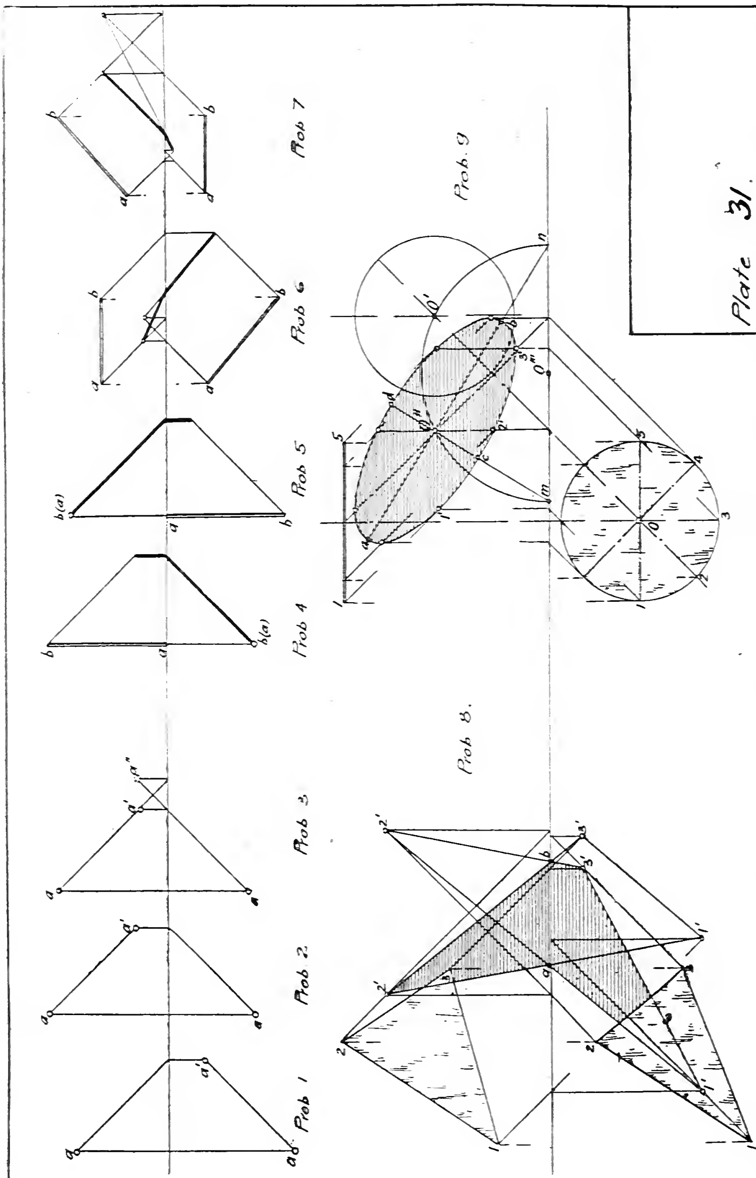
(a) The umbra of a point is a line.

(b) The umbra of a line is a plane.

(c) The umbra of a plane is a solid.

(d) The shadow of an object upon another object is the intersection of the umbra with the surface of the second object. For instance, shadow of sphere is an ellipse, rays being inclined to plane, umbra being a cylinder.

4. *Ray of light.* The sun is the supposed source of light, and being at an infinite distance the rays of light are assumed to be


Prob 1
Prob 2
Prob 3
Prob 4
Prob 5
Prob 6
Prob 7
Prob. 8.
Prob. 9
Plate 31.

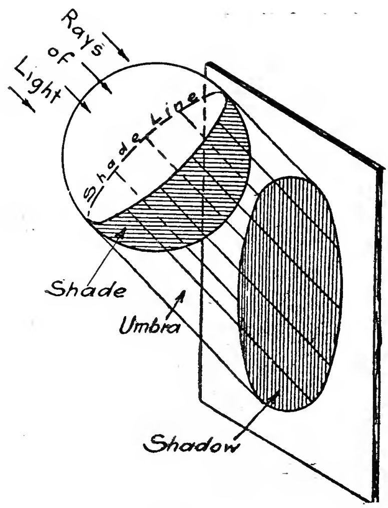


FIG. 31.

parallel. Although the direction of the rays may be chosen arbitrarily, it has become customary to consider the rays as passing from the upper left over the left shoulder of the observer upon the object and forming an angle of 45° with the horizontal line in both plan view and elevation. The true angle which the rays make with $P_1 = \alpha = 35° \ 15'$, which value has been found by computation.

5. *Shade line.* The line of separation betwen the portion of an object in light and the portion in shade is called the *shade line.* It is made up of the points of tangency of rays of light tangent to the object.

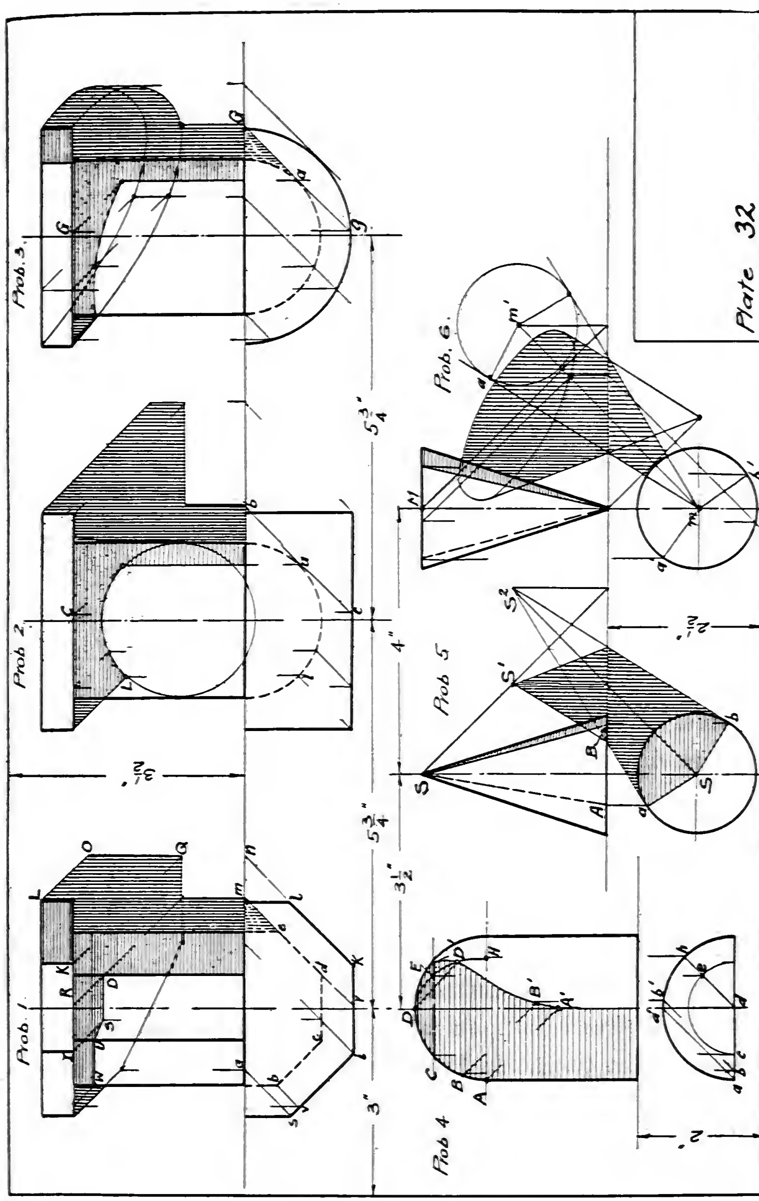
6. The shadow of the object is the space enclosed by the shadow of the shade line. In Fig. 31 the shade line of the given sphere is a great circle of the sphere. The shadow of this great circle on the given plane is an ellipse. The portion within the ellipse is the *shadow* of the sphere.

Plate 31. Points, Lines and Planes.

Prob. 1. Point nearer P_1.

Prob. 2 and 3. Point nearer P_2.

The shadow of a point falls always upon the plane, which is nearest to the point. In Prob. 3 the shadow of the point in plan is indicated and would be in a', provided the point were further removed from P_2. a''-a', of course, must be horizontal.


Prob. 1
Prob. 2
Prob. 3.
Prob. 4
Prob. 5
Prob. 6.
Plate 32

Prob. 4, 5, 6 and 7. Shadows of lines. The lines purposely are shown with double lines, to bring out the construction.

Prob. 4. Line $\perp$ P_1. Shadows indicated by heavy lines.

Prob. 5. Line $\perp$ P_2.

Prob. 6. Line $\|$ P_1, inclined to P_2.

Prob. 7. Line $\|$ P_2, inclined to P_1.

Determine shadow of two points of line (end points) and the connecting line is the shadow of the line.

Prob. 8. Shadow of plane (triangle).

Determine the shadow of the three corners 1, 2, 3 upon the planes of projection, then the triangles 1′-2′-3′ will be the shadows in plan and elevation, and only as much as appears on their respective plane will be visible and is shade-lined. The two shadows must intersect each other on the X-axis at *a* and *b*.

Prob. 9. Shadow of circular plane.

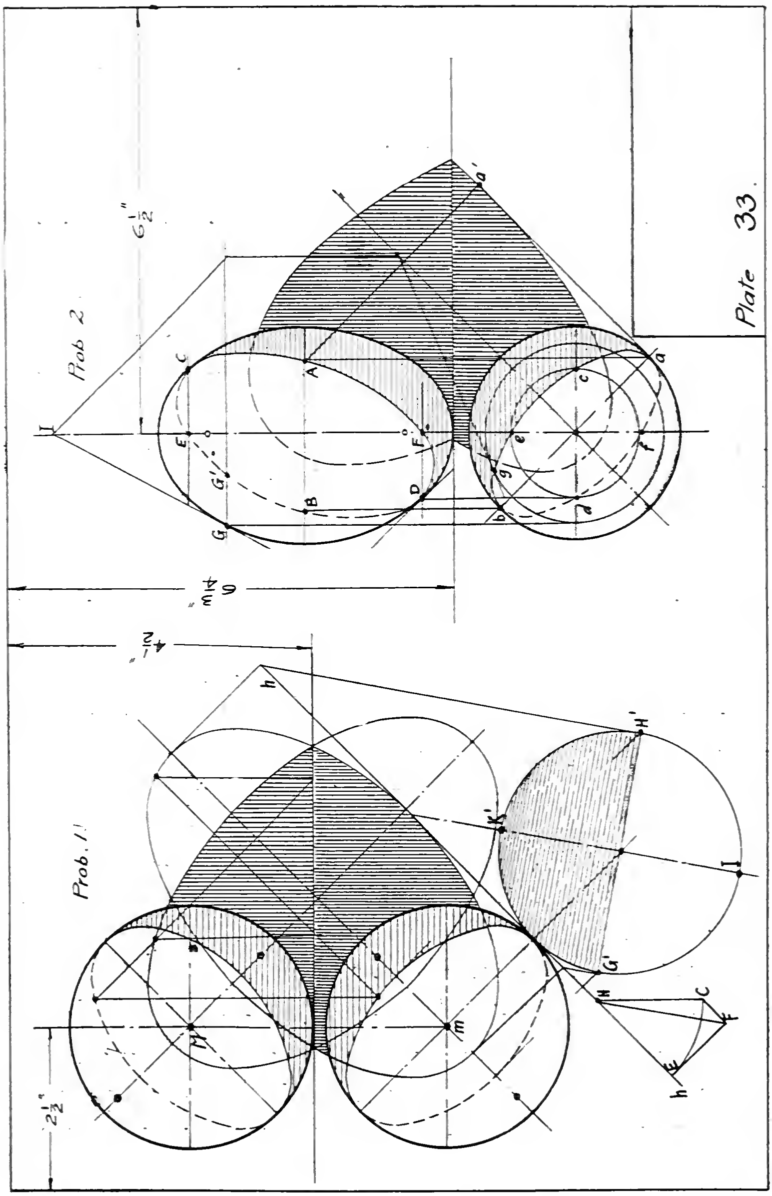
Plane is $\|$ to P_1 and the distance so chosen, that the shadow of the circle falls completely upon P_2. Choose any number of points on the circle (8) and find their shadow upon P_2. The points 1 to 8 will give us shadow 1′ to 8′, forming an ellipse.

To determine the two axes of the ellipse cast the shadow of the circle upon P_1, which is a circle O' of the same diameter as O. Draw circle O''' passing through centres O' and O'' and draw mO'' and nO'', cutting the ellipse in c and b. Then a-b is the major and c-d the minor axis of the ellipse. After the axes have been thus determined all other points of the ellipse may be found without the former method.

Plate 32. Prisms and Pyramids.

Prob. 1. *Octagonal prism with octagonal flange.*

This object has its edges either vertical to or parallel to the co-ordinate planes and we can determine immediately the light and shade faces by applying to the object the projections of the


Prob 2
Prob. 1
Plate 33.
6 1/2"
6 3/4"
4 1/2"
2 1/2"

ray of light. These determine the *shade lines*. Then cast the shadows of these shade lines.

Considering first the flange, it is evident that its top, left hand and front faces will receive the light, that the lower and right hand faces will be in shade.

By casting the shadow of the flange, draw *l-n* at 45°, also the projection of the ray from *L*, which gives us the point *o* corresponding to *n*. The ray from *K* terminates the shadow at *Q*.

By producing plane *d-e* to *r* and drawing *s-a*, it is evident that the edge *s-i-r* casts its shadow upon the prism. The ray from *R* gives *D*. From here the shadow is horizontal to the ray from *I* on *S*. Point *U* is found from the corresponding ray passing through *c*, point *W* from *v-b*. As a straight line is determined by two points lying in the line, it is evident that if we cast the shadow of the two ends of a line and draw straight lines between such points, such lines will be the required shadow.

Prob. 2. *Cylinder with square flange.*

By drawing *c-b* tangent to the cylinder we obtain the shade line *a* in the elevation. *b* is the shadow on the wall. The shadow of the flange will be cast partly on the cylinder and on the wall. The shadow on the cylinder is part of a circle of the same radius as the cylinder.

Prob. 3. *Cylinder with round flange.*

Shade line *a* and shadows *G* are found as in Prob. 2 by drawing a *G* tangent to cylinder. To find points for the curve which is the shadow on cylinder and wall cast by the flange, any number of rays are projected as indicated in the illustration.

Prob. 4. *Niche.*

The niche is half of a hollow cylinder topped by quarter of a hollow sphere. The shade for the cylindrical part is found by projecting rays *a, b,* etc., in both views.

To find the shade for the spherical part, a number of cutting

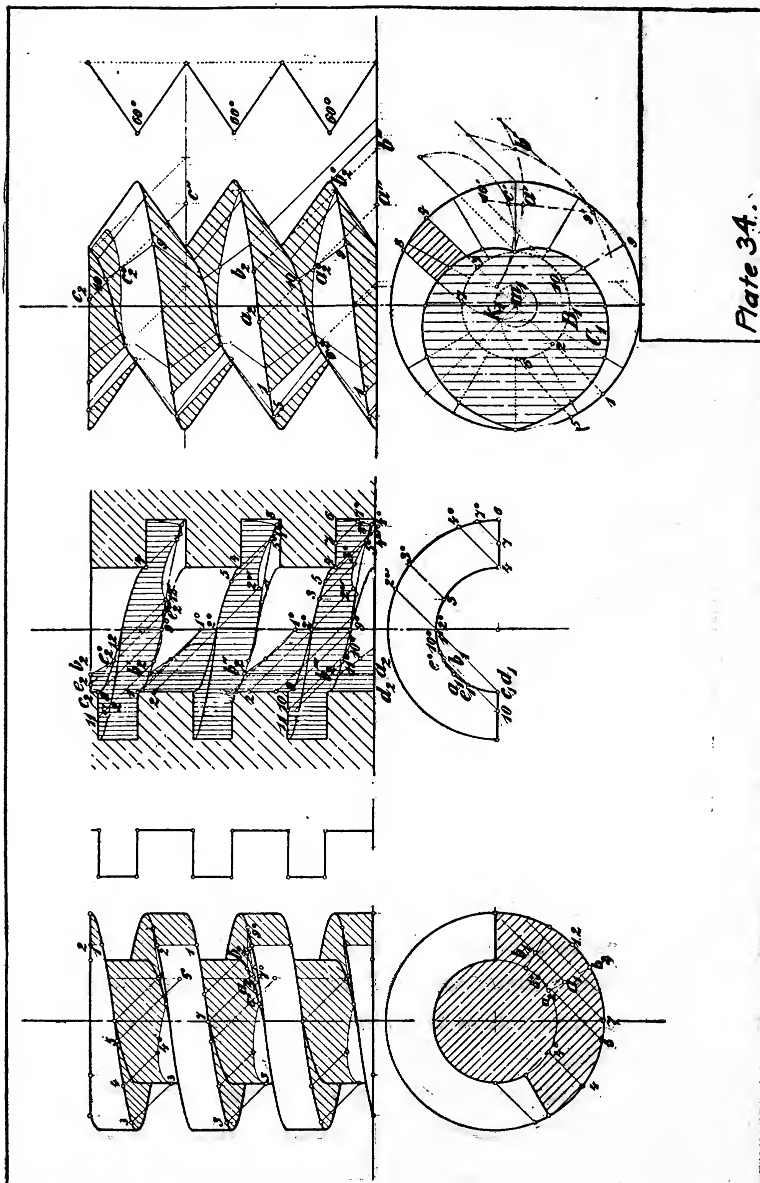


Plate 34.

planes are passed through the solid, perpendicular to P_1. in the direction of the horizontal projection of the light rays. The intersections of these planes with the niche appear as curves in the elevation, for instance, *D E H*. The ray from *D* intersects this curve in *D'* and furnishes a point for the shade curve.

Prob. 5. *Cone.*

Part of the shadow falls on P_1 and P_2, according to the position of the cone on P_1. By projecting the rays from the apex, point S^1 is found and by producing the ray in the plan we find S^2 from which we draw tangents to the base of the cone, giving the shade lines *a* and *b*.

Prob. 6. *Cone standing on vertex.*

The shadow in the plan is found by first finding m^1, which is the projection of the rays from *m* and *M*. M^1 being the center of a circle with radius equal to that of the base, draw tangents *ma* and *mb* and draw a^1m and b^1m parallel to am^1 and bm^1. a^1m and b^1m are the shade lines of the cone.

To find the shadow in the elevation, which is part or the whole of an ellipse, according to the position in the plan, draw the projections of any number of rays as indicated in the illustration. (See also Prob. 9, Plate 31.)

Plate 33. Sphere and Ellipsoid.

Prob. 1. *Sphere.*

If we draw a cylinder tangent to the sphere in the direction of the rays of light, its diameter will be the same as the diameter of the sphere and its axis will pass through the center of the sphere. Each element will touch the sphere in one point and all these points lie on a plane perpendicular to the rays of light, and form a great circle of the sphere. The problem is simply that of finding the intersection of a cylinder with a plane. Upon *h-h* in the direction of the rays of light as a new horizontal, draw the sphere in the elevation and find the true angle of the rays of

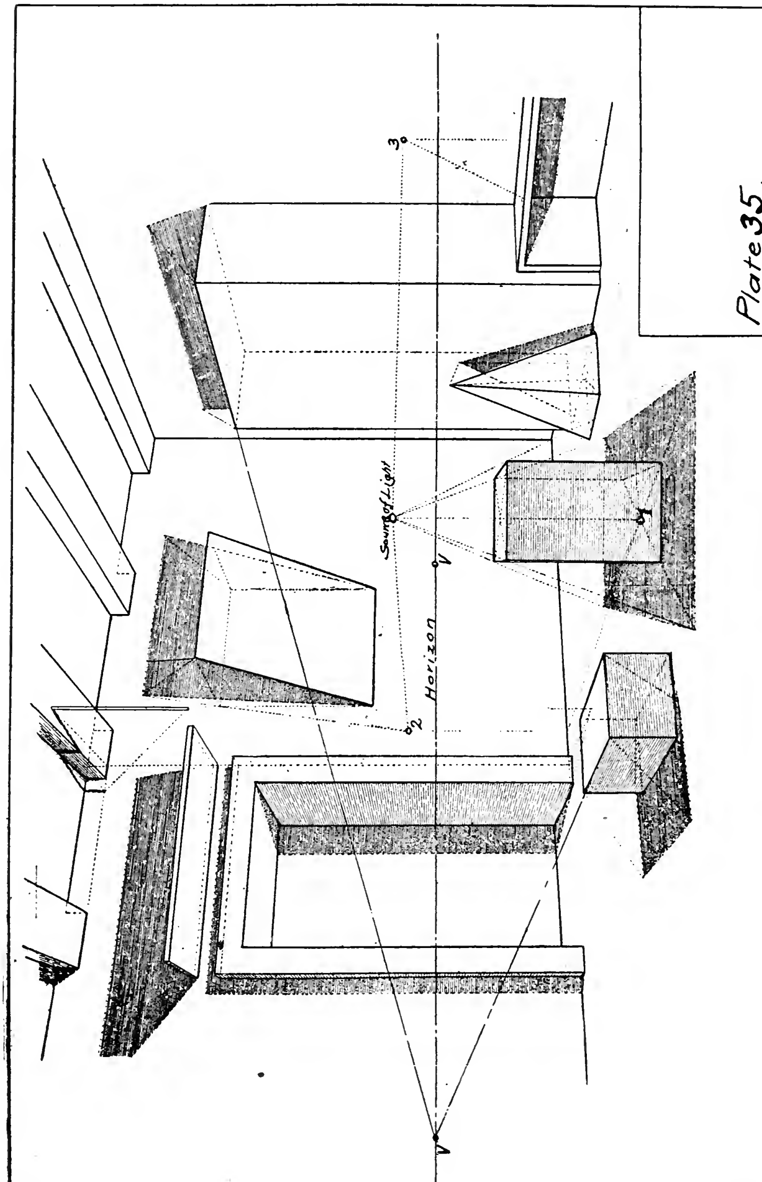


Plate 35.
Horizon
Source of Light
V
V
1
2
3
4

light, which passes through H^1 parallel to F-H. G^1 and H^1 are the points indicating the extreme shade lines of the circle and when projected upon circle m determine the major axis of the elliptical shade.

The hemisphere G^1 K^1 H^1 is in shade and the other hemisphere in light. At I is the greatest light, at G^1 H^1 is the greatest shadow, which can be best illustrated by dividing the sphere into a number of zones, and giving them a gradual shading.

Prob. 2. *Ellipsoid.*

In the elevation the ray is tangent in C and D, giving us E and F; in the plan we obtain in the same way a b e f d c.

To obtain further points for the shade lines we construct a number of cones tangent to the surface, for instance, I G, and we obtain by the same method as in Prob. 5 points g and G^1.

Plate 34. Screw Surfaces.

Prob. 1. Square threaded screw.

Prob. 2. Square threaded nut.

Prob. 3. V-threaded screw.

These are rather difficult problems, as no further information is given. They need not be taken up in the regular course of study, although they form an excellent test of how far the student is enabled to solve problems without further aid, solely using his knowledge gained in previous work.

Shadow Perspective.

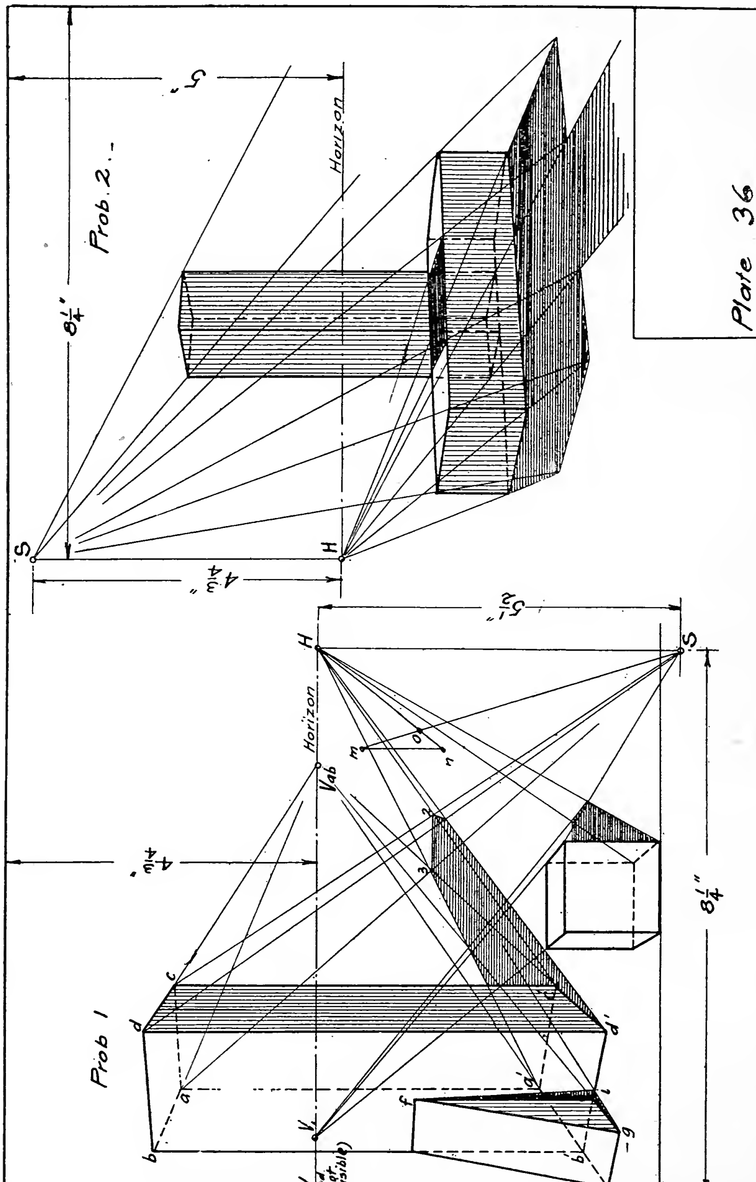
We distinguish here between a natural source of light (sun) and an artificial source (for instance, a candle). In the first case the rays of light enclose prisms, in the latter case pyramids.

The laws of shades and shadows apply here too, for instance:

The shadow of a point is there where its ray pierces the plane.

Straight lines cast straight shadows upon planes.

Parallel lines cast parallel shadows upon the same plane.


Prob. 2.
Horizon
8 1/4"
5"
4 3/4"
S
H
Plate 36
Prob 1
Horizon
4 1/4"
5 1/2"
8 1/4"
V_{ab}
V_{bd} (not visible)
V_1
a
b
c
d
a'
c'
d'
f
g
m
n
o
1
2
3

The shadow of a straight line, which is parallel to a plane, cast upon the same plane is parallel to the line.

If a straight line is perpendicular to a plane, its shadow takes the direction from the point where a vertical ray pierces the plane (foot point of ray of light).

If we pass a plane through the light and the vertical line this

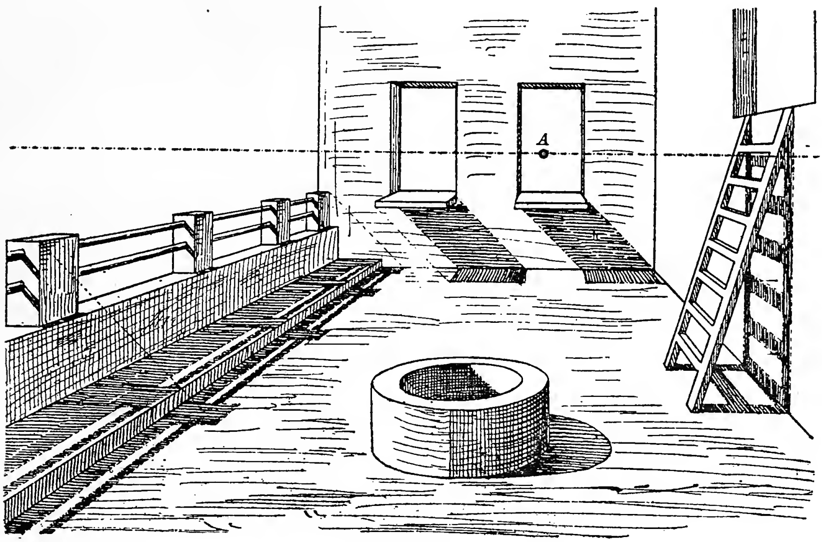


FIG. 31-A.

plane will intersect the horizontal plane in a straight line containing the foot point of the ray.

If the sun is the source of light the foot point for all horizontal planes lies perpendicular under the sun in the height of the eye.

Plate 35. Shadow Perspective I.

The perspective drawing of an interior and the source of light (candle) being given.

Locate first the foot points 1, 2, 3 upon the various planes represented by walls, floors, ceiling, etc., and continue as outlined in the drawing.

In Fig. 31-A the sun is the supposed source of light and located high above the picture plane. In this case all rays may be drawn parallel.

Plate 36. Shadow Perspective II.

Prob. 1. *Point S below the horizon.*

The prism rests with its base upon P_1. One face of the cube lies in the picture plane, thereby having only one vanishing point which is at V_1.

The point of sight is supposed to be opposite to H at the proper distance and a ray of light to pass through it, which pierces the picture plane in S. Therefore S is the vanishing point for the projection of all other rays. cS, dS, aS appear therefore as the projections of those which pass through a, c, d. Imagine a plane passed through the vertical plane dd, and through the ray dS, we recognize SH as its trace and d^1H as the line of intersection with the horizontal plane. dS and d^1H being in the plane dd^1SH, intersect in I. This is the shadow which d casts upon the horizontal plane. On the same plane lies d^1I, which is the shadow of d^1d.

A vertical plane through cc^1 and cS cuts the horizontal plane in the line c^1H, upon which at 2 the shadow of c must lie. Likewise a^1H is the direction of the shadow of a^1a and on this line the point 3 is the shadow of a. 1-2 is shadow of dc, but as this line is horizontal, both must be parallel and have Vab as vanishing point. Line 2-3 as shadow of c-a must also be parallel and vanish toward the same point Vbd.

The construction of the shadow of the cube is shown in the drawing. m-n is a vertical line, with n upon the horizontal plane. m-n may represent the height of the human figure standing at n. no is direction and length of its shadow cast on the horizontal plane.

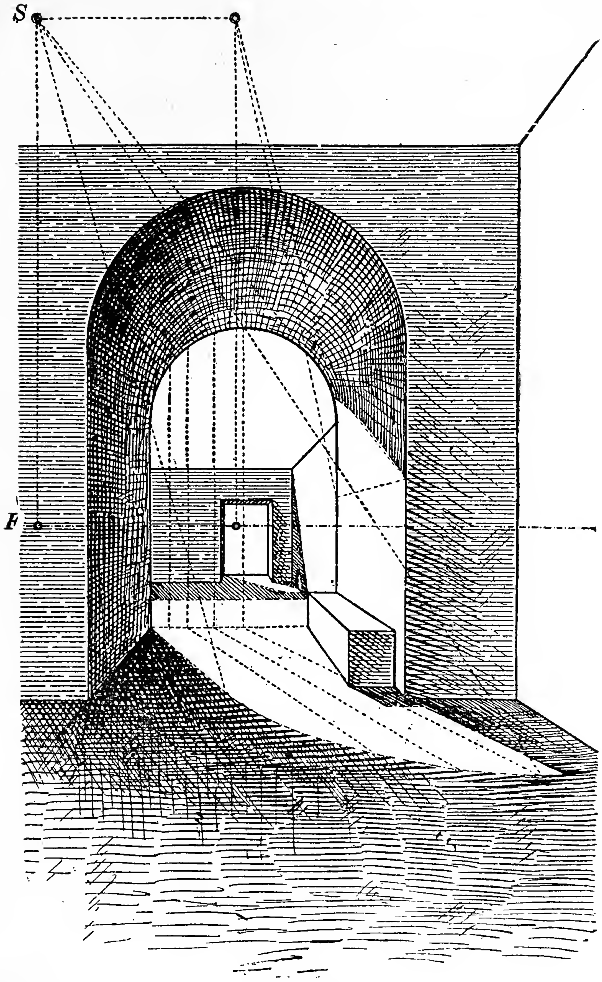


FIG. 31-B.

If the vanishing point S for all rays of light lies below the horizon it indicates that the sun is behind the observer and that the fronts of all objects are in light.

If, on the other hand, S were above the horizon the light

would come from behind and the front of all objects would be in shade.

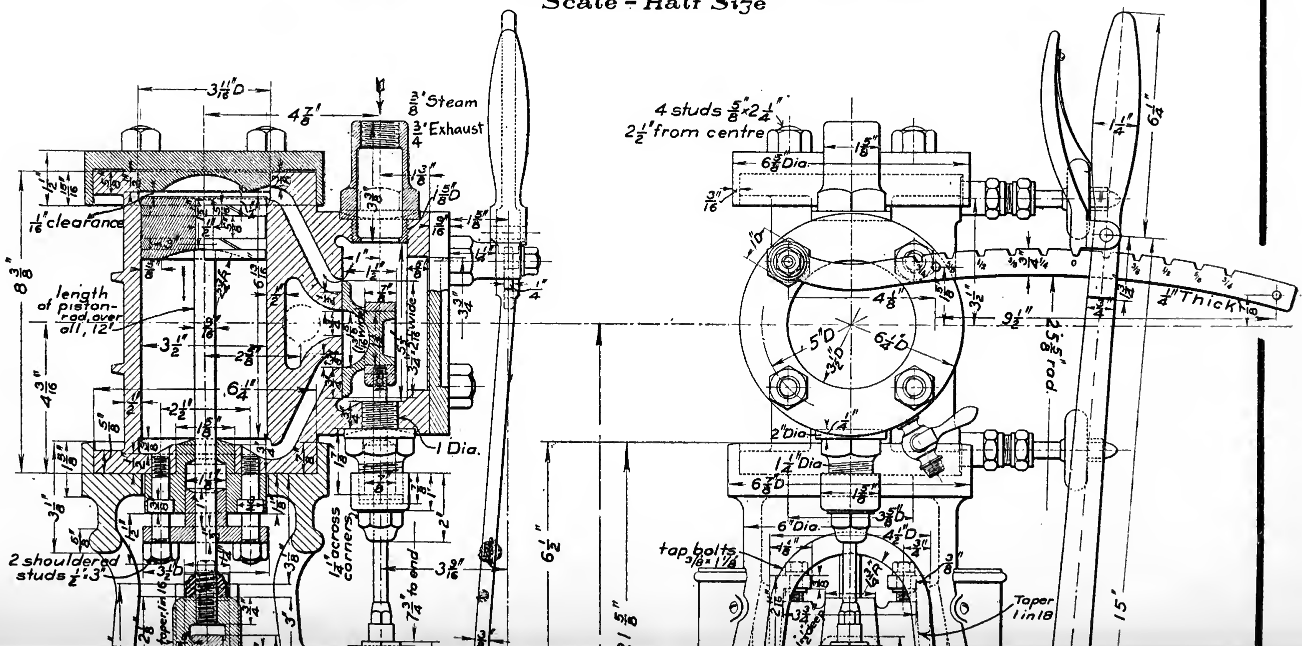
Prob. 2. *Point S above the horizon.*

Construction of shades and shadows may be understood from drawing.

Another problem worked out on this principle is shown in Fig. 31-B.

$3\frac{1}{2} \times 5$ Marine Engine

Scale - Half Size



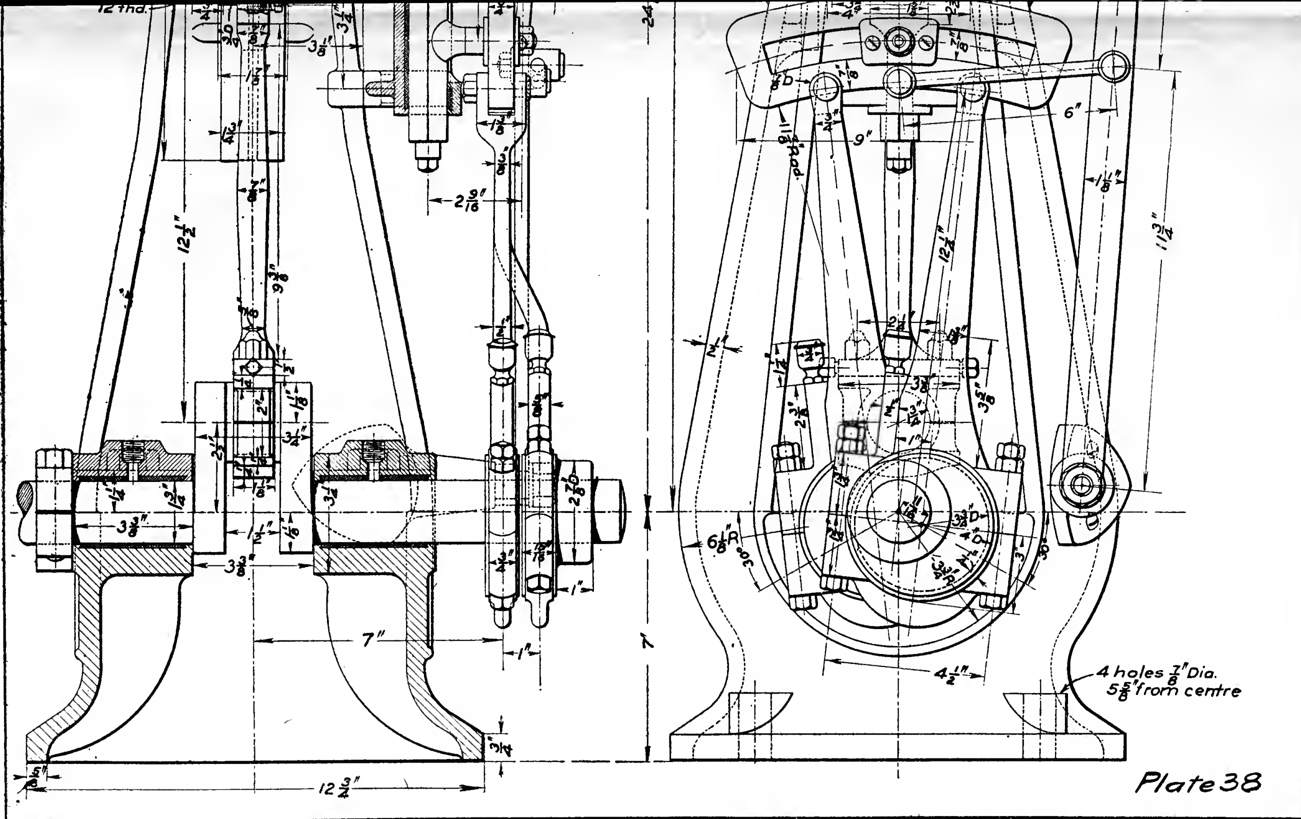


Plate 38

CHAPTER VI.

ADVANCED MECHANICAL DRAWING.

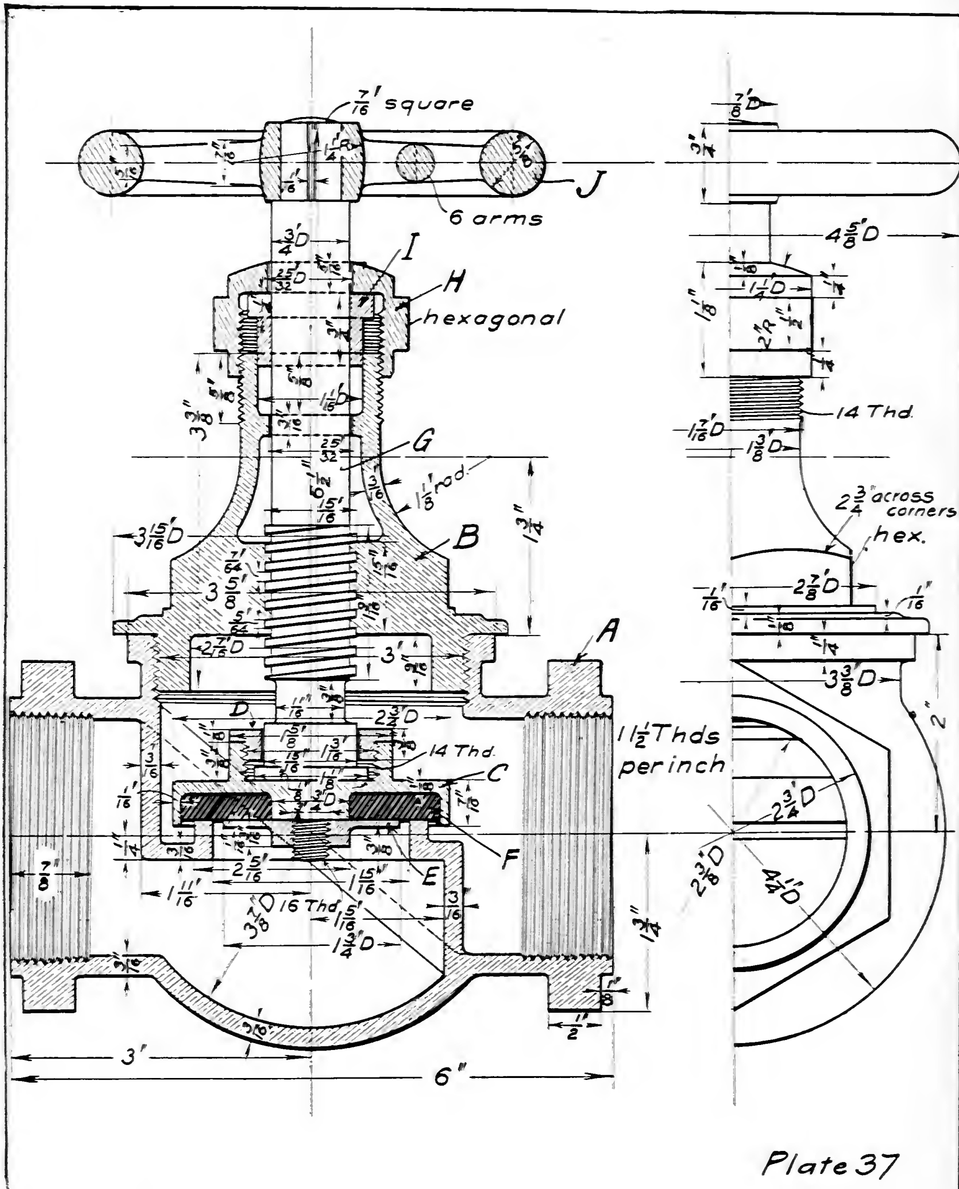
A—Working Drawings.

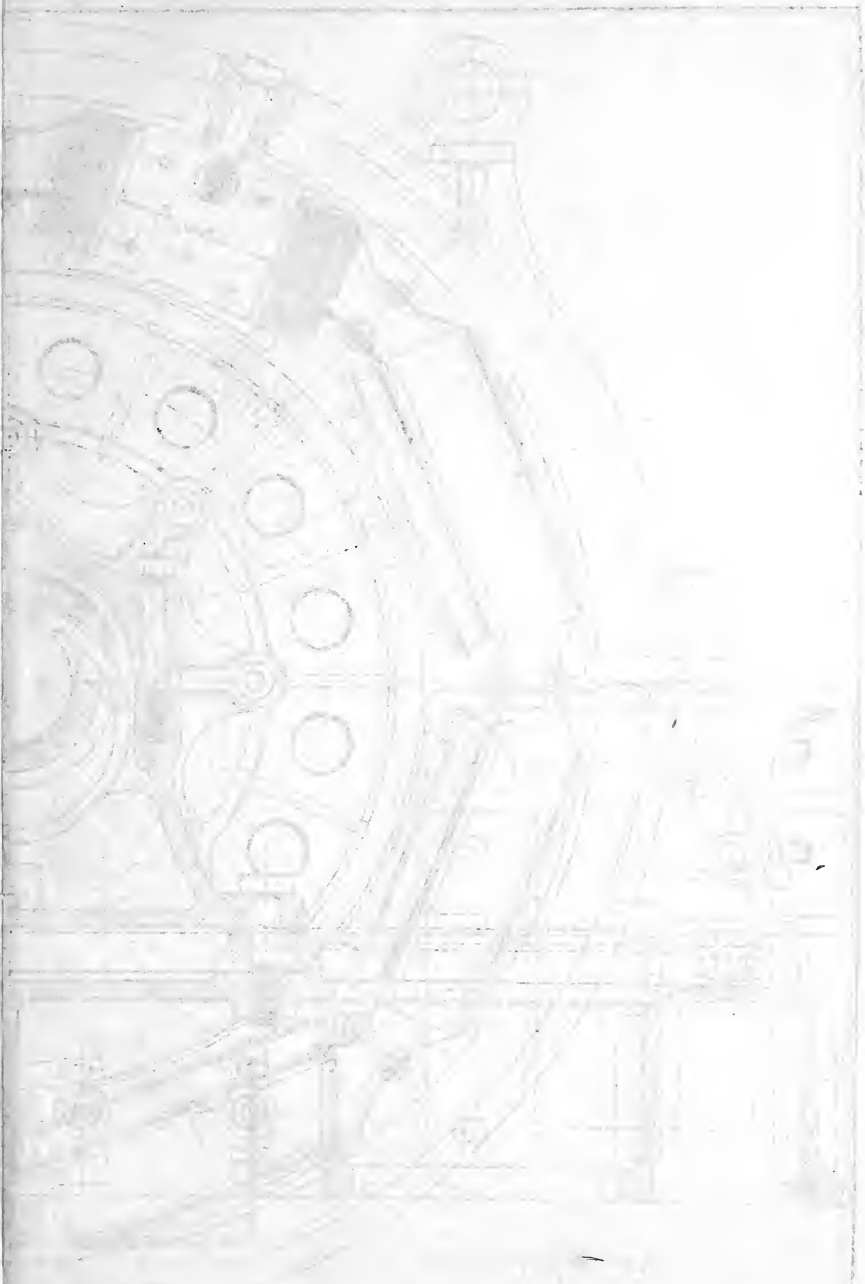
The problems on the next five plates, 37, 38, 39, 40 and 41, are good examples of assembly drawings. In the absence of suitable models they may serve as drawing plates. Steam engine and generator should be worked out in form of a complete set of detail drawings, each detail being represented in as large a scale as possible (preferably full size). From his own detail drawings the student then should work out the different views of the engines complete. And here, again, the author wishes to emphasize the great importance of making intelligible freehand sketches of the various machine parts from the given assembly drawings or, still better, from actual machines. These sketches are to be entered in a special notebook kept for the purpose. The student should also record in this book any new rule for proportioning machines, tables, formulas and standards of machine drawing, relating to bolts, castings, pattern, machine shop work, etc., always stating the source of his information in each case for future reference.

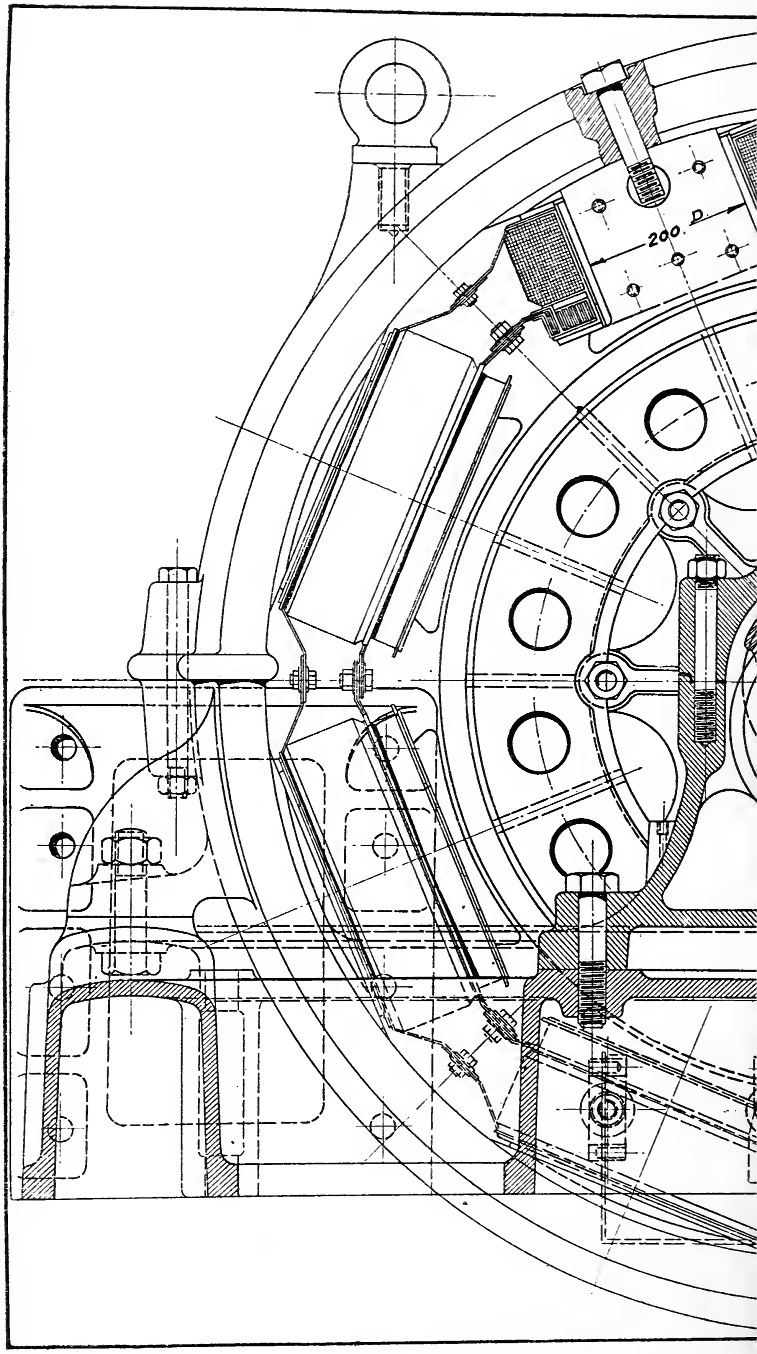
At this stage of our work the student should take up the study of elementary machine design and strength of materials, and in connection with his drawings should peruse good text books on machine design, steam engines, etc., as collateral reading. Only the most important facts in connection with the drawing plates are touched upon here so as to stay within the scope of this book.

Plate 37. 2″ Globe Valve.

Make working drawing of every detail in two views, scale full size, also assembly either full or half size, depending on space available. Only *over-all* dimensions to be inserted in assembly. Complete list of material: *A* Body, *B* Bonnet, *C* Disk


7/16" square
6 arms
J
I
H
hexagonal
G
1 1/8" rad.
B
A
D
14 Thd.
C
F
E
3 7/8" D 16 Thd.
1 1/2" Thds per inch
14 Thd.
2 3/4" across corners hex.
3"
6"
Plate 37





200. D

7/8

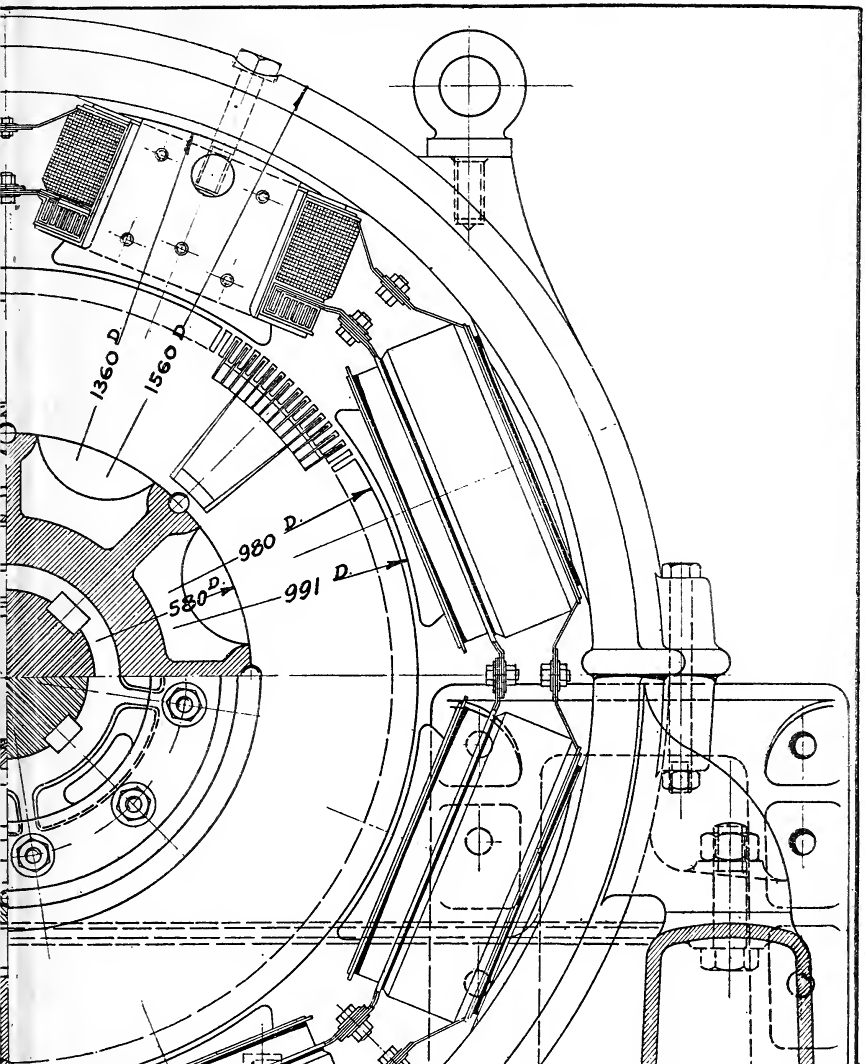
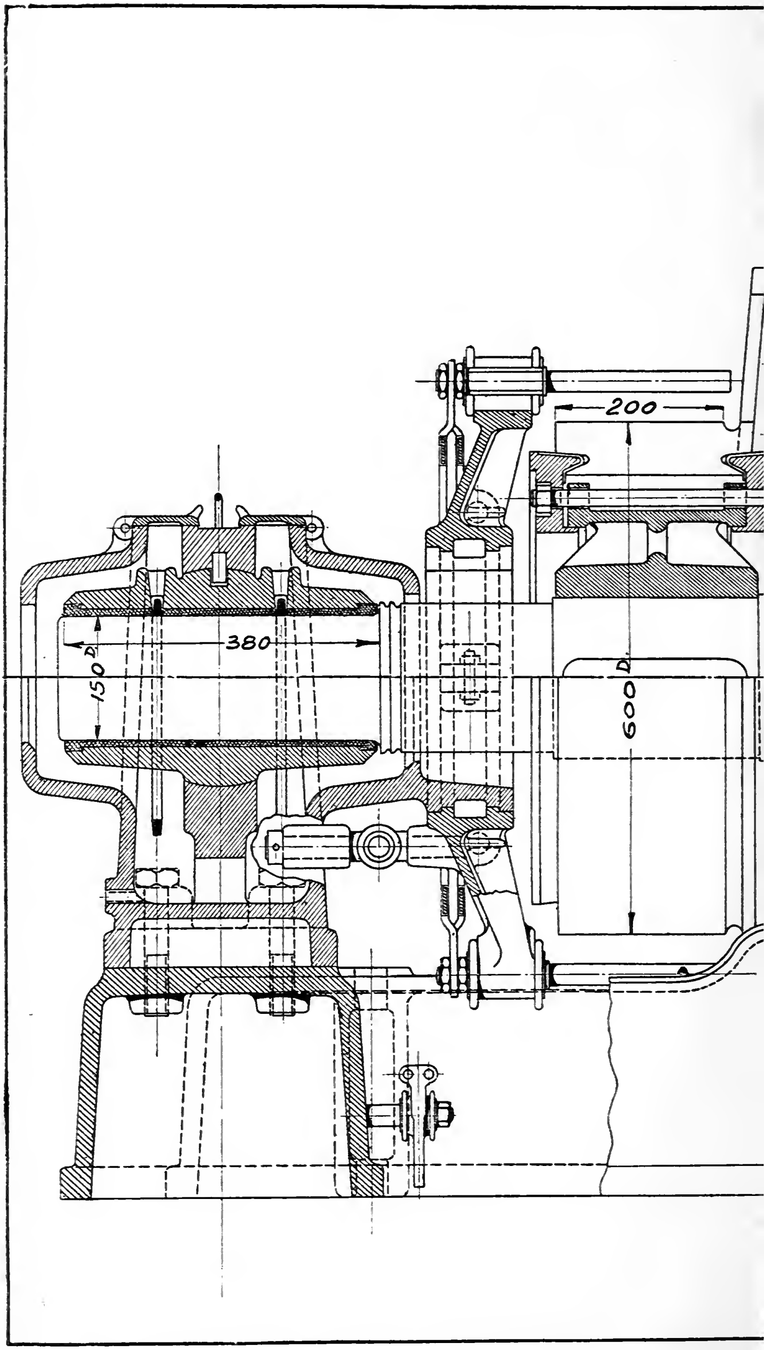


Plate 39.



200
380
150 D
600 D

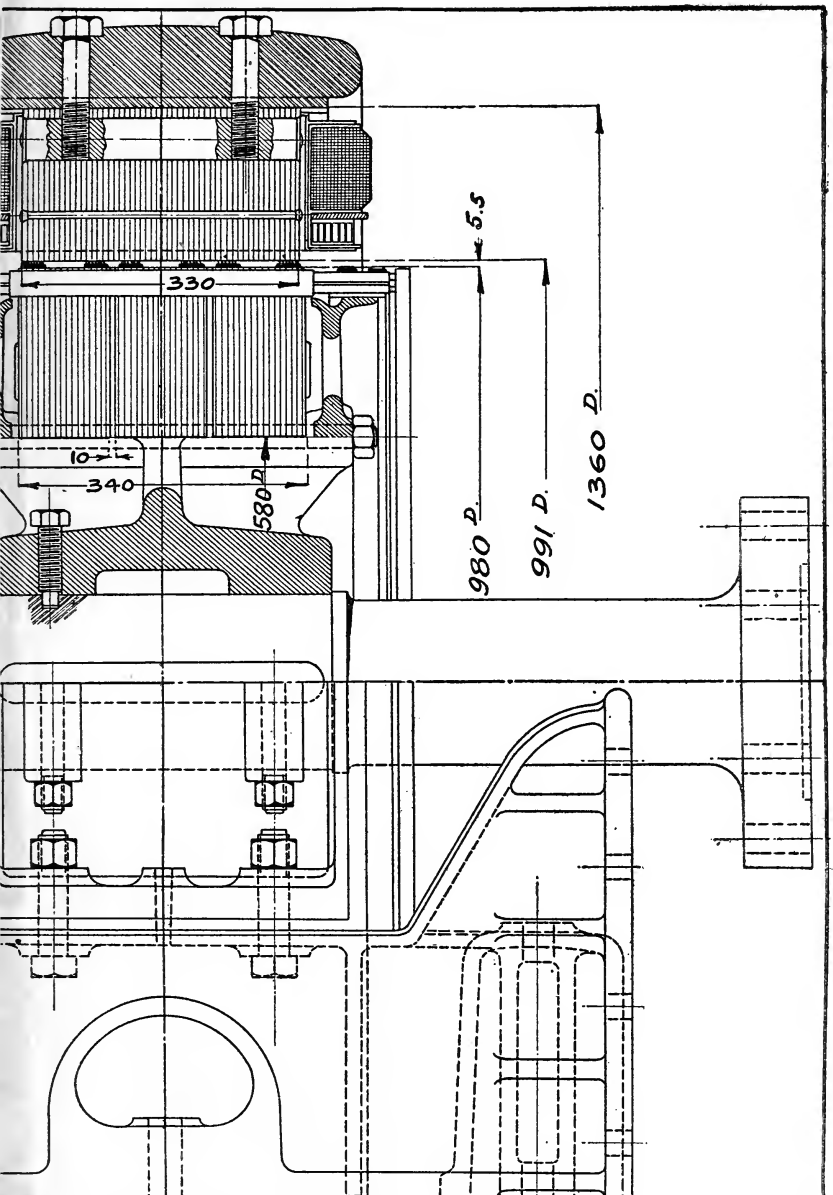


Plate 40.

Holder, *D* Lock Nut, *E* Disk Nut, *F* Valve Disk, *G* Spindle, *H* Gland Nut, *I* Follower, *J* Hand Wheel. (Don't fail to get manufacturer's catalog!)

Plate 38. Marine Steam Engine.

Description: The steam engine converts heat into mechanical work.

Its working is briefly as follows: A piston is moved in a cylinder by the pressure of steam alternately in opposite directions. This reciprocating motion is converted into rotary motion through the connecting rod and crank. A slide valve in the steam chests admits steam alternately to both ends of the cylinder through the steam ports at either end.

When the valve is in the position shown steam enters the upper end of the cylinder and drives the piston downwards. At the same time the lower end is connected with the exhaust pipe, through which the steam escapes into the atmosphere (or into a condenser in case of a condensing engine).

The slide valve is moved by an eccentric which acts like a small crank. It is set in such a way that steam is shut off to either end of the cylinder before the piston has completed its stroke (point of cut-off). The motion of the piston is continued during the remainder of the stroke by the expansive force of the steam.

As this particular type of engine is a marine engine it must be able to reverse its motion. This is accomplished by a peculiar arrangement of two eccentrics operated by a combination of levers, which is called the "Stevenson Link Motion." The ends of the eccentric rods are connected by a link on which slides a block to which the valve rod is connected. By shifting the link either eccentric rod can be brought opposite the slide block and then the valve receives motion from that eccentric (*full speed forward or full speed reverse*). In any intermediate position of

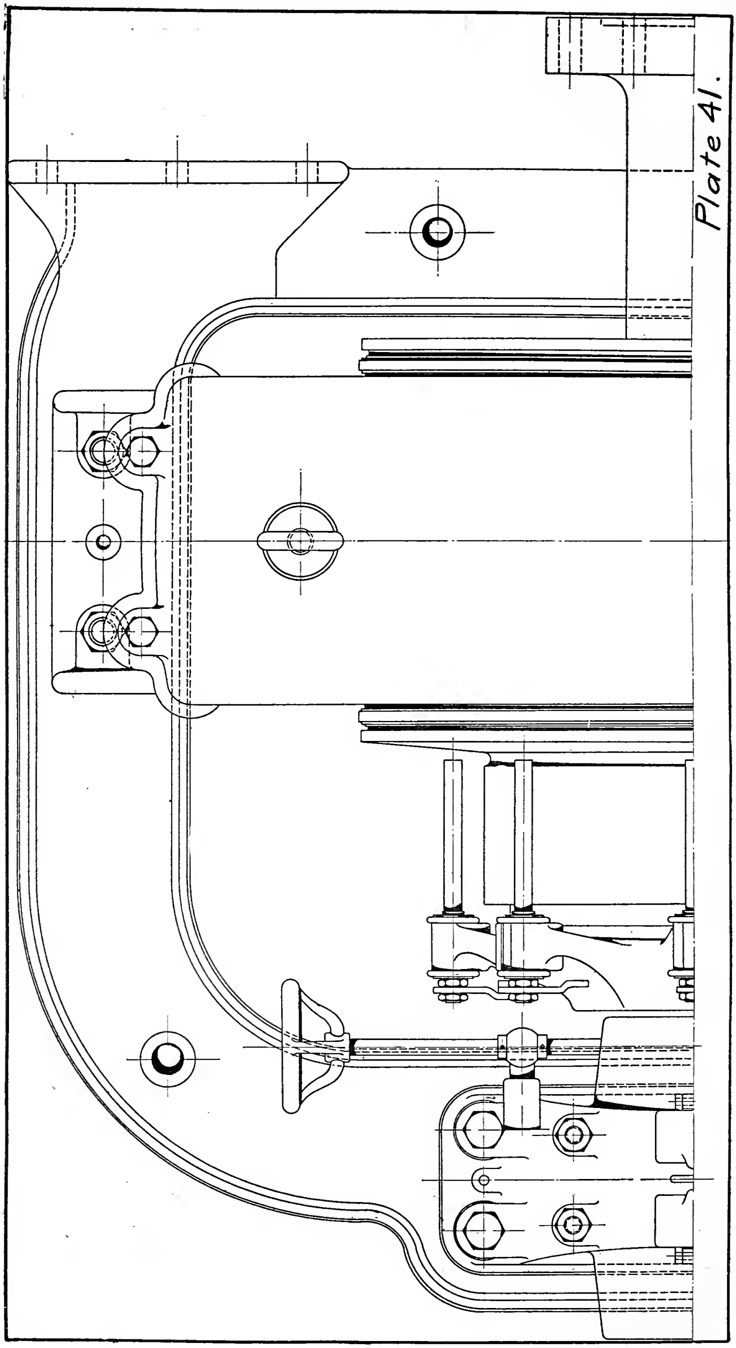


Plate 41.

the slide block it gets a motion due to both eccentrics, travel of the valve is reduced and cut-off occurs earlier. Result: *Engine slows down.* Exactly at the centre the motion of the valve is too small to admit steam effectively. Result: *Engine stops.*

Make full set of working drawings of each detail.

Redraw assembly with only over-all dimensions inserted.

Plates 39, 40, 41. D. C. Generator.

Description: A generator (dynamo) converts mechanical energy into the energy of currents of electricity.

It consists of three essential parts:

(a) The *field magnet* to produce a powerful magnetic field.

(b) The *armature,* a system of conductors wound on an iron core and revolving in the magnetic field in such a manner that the magnetic flux through these conductors varies continuously.

(c) The *commutator,* by means of which the machine is connected to the external circuit.

Specifications: 165 k. w., 550-500 volt, 300 amp., 400 rev. per minute.

Eight poles with 1,700 windings of 1.8 mm. wire.

Armature of 98 cm. diameter, length of iron 32 cm., height of iron less height of teeth 16.6 cm.

Number of conductors on periphery 500, measuring 2.4 x 12 cm.

Number of grooves 250, measuring 3.4 cm. deep by 0.5 cm. wide.

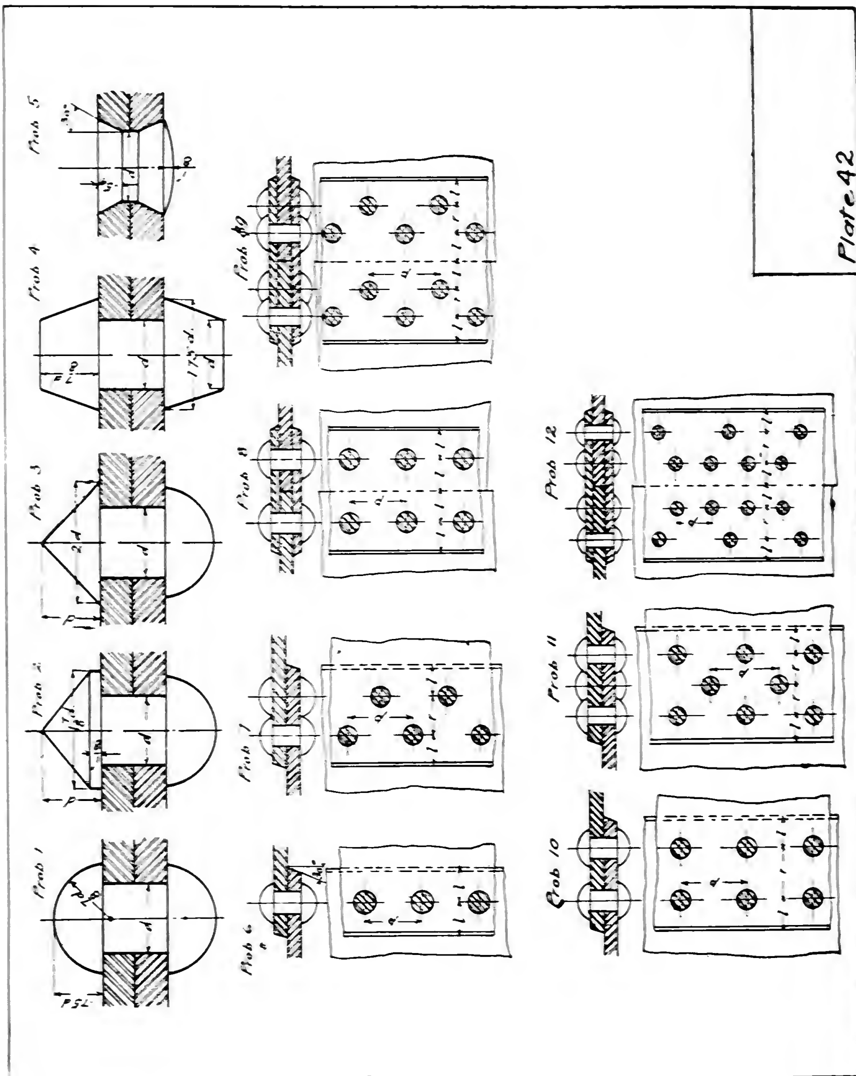
Commutator of 60 cm. diameter, length 20 cm., 250 segments.

Make full set of working drawings to decimal or inch scale.

B—Elementary Designing and Construction.

(*a*) Riveted Joints and Structural Work.

A riveted joint is, unlike a bolted joint, a permanent fastening. The plates of such a joint overlap and have one or more rows of


Prob 1
Prob 2
Prob 3
Prob 4
Prob 5
Prob 6
Prob 7
Prob 8
Prob 10
Prob 11
Prob 12
Plate 42

rivets, arranged either zig-zag or opposite each other. The plates may butt against each other and have either single or double welt strips.

Rivets and Rivet Holes.—Usually the rivet is 1/16 in. less in diameter than the hole. All holes should be drilled after the plates have been bent or flanged and put together in their proper places.

Symbols.—d = dia. of rivet, t = thickness of plates, t = thickness of welt strip, p = pitch, 1 = lap.

In each case l = 1½d.

Plate 42. Riveted Joints.

Prob. 1 to 5. *Common forms of rivet heads:* (1) Button, (2) and (3) Steeple, (4) Conical, (5) Countersunk.

d=1″ t=9-16″. Scale, full size.

Prob. 6. *Single riveted lap joint.*

d=t+⅜ p=2d+¼, for iron plates and iron rivets.
d=t+7-16 p=2d+¼, for steel plates and steel rivets.

Prob. 7. *Double riveted lap joint* (zig-zag).

d=t+5-16 p=3d+¼, for iron plates and iron rivets.
d=t+⅜ p=3d+⅛, for steel plates and steel rivets.

Prob. 8. *Single riveted butt joint* with double welt strips.

d=t+¼ p=3d+¼, for iron plates and iron rivets.
d=t+5-16 p=3d+⅛, for steel plates and steel rivets.

Prob. 9. *Double riveted butt joint* with double welt strips.

d=t+¼ p=3d+1, for iron plates and iron rivets.
d=t+5-16 p=3d+¾, for steel plates and steel rivets.

Prob. 10. *Double riveted lap joint* (chain spacing).

d=t+5-16 p=3d+¼, for iron plates and iron rivets.
d=t+⅜ p=3d+⅛, for steel plates and steel rivets.

Prob. 11. *Treble riveted lap joints.*

d=t+5-16 p=3d+⅞, for iron plates and iron rivets.
d=t+⅜ p=3d+½, for steel plates and steel rivets.

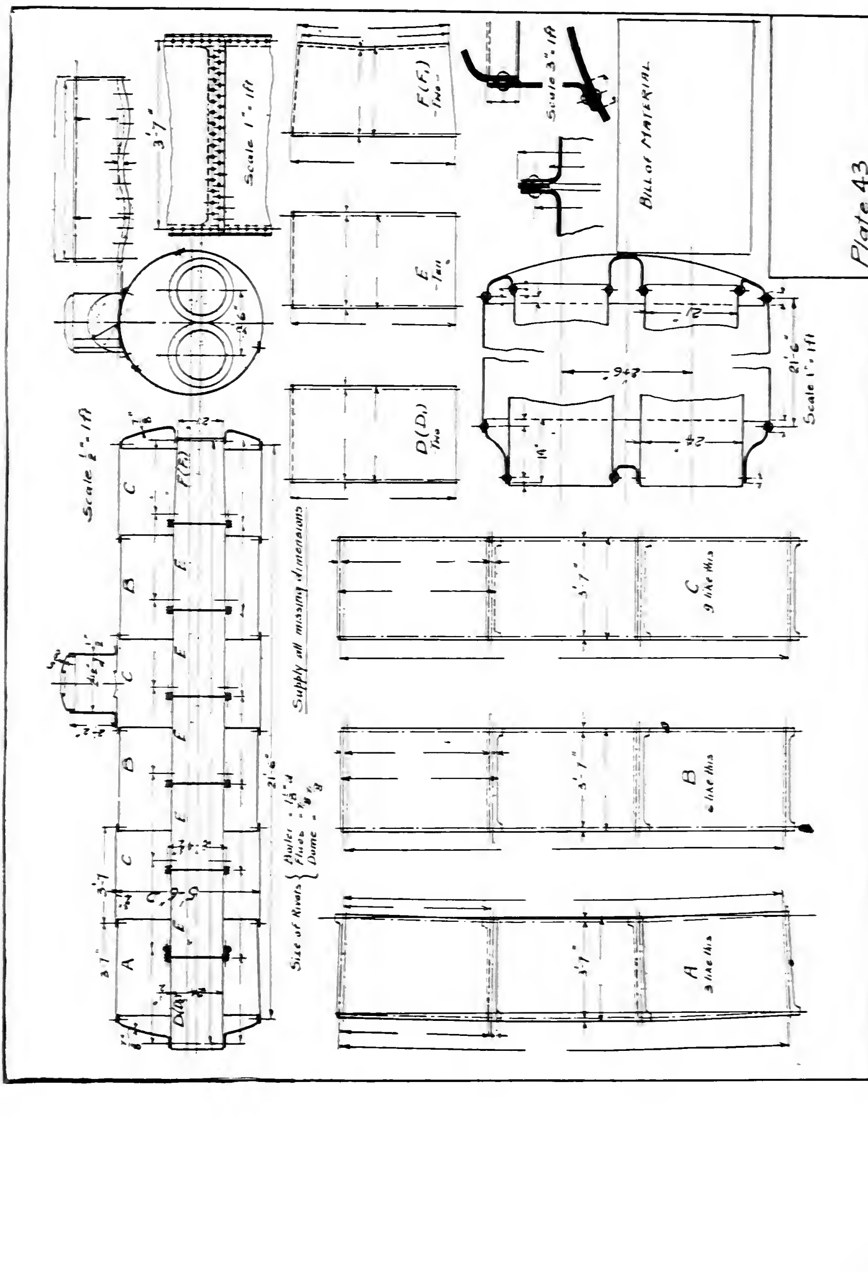


Plate 43
Bill of Material
Scale 1" = 1 ft
Scale 3" = 1 ft
Scale 1/2" = 1 ft
Supply all missing dimensions
Size of Rivets
A
3 like this
B
4 like this
C
9 like this
D(D₁)
F(F₁)
E
21'-6"
3'-7"

Prob. 12. *Double riveted butt joint* with double welt strips.

$d = t + 1/8$ $p = 2d + 1/4$, for iron plates and iron rivets.

$d = t + 3\text{-}16$ $p = 2d + 1/4$, for steel plates and steel rivets.

The pitch in each case has been calculated so as to make the shearing strength of the rivet equal the tensile strength of the plates. $t_1 = 5/8\ t$.

Distance between adjacent rivets, measured from centre to centre of rivet, whether in the same or different rows, should not be less than 2d, from which determine value of *c*. Assume different values for *d* in each case. Use steel plates and steel rivets. Scale 6″ = 1′.

Plate 43. Two-Flue Boiler.

Make complete working drawing as outlined. Each sheet for boiler, flues and dome to be fully and accurately dimensioned. List of material. Scale to suit paper.

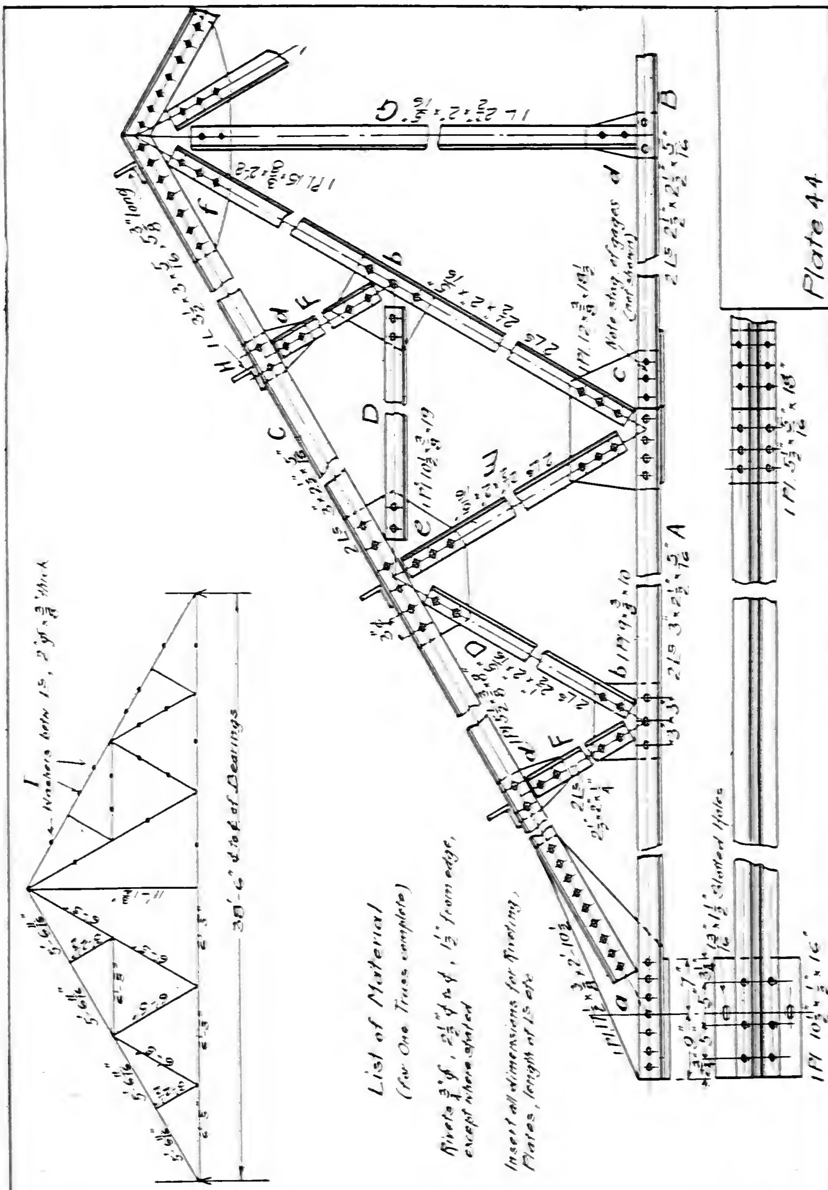
Structural Drafting.

Structural drafting is generally subjected to the same requirements as mechanical drawings. A few special characteristics may be mentioned, however.

Shade lines are seldom used; they are apt to destroy the accuracy of the diagram in scaling. Also, the simplest form of *lettering* is adopted, owing to the fact that numerous notes are necessary.

Structural frames are made of rolled forms, designated by the forms of their sections. The shapes commonly used are plates and bars of square, round, flat, angle, channel and Z sections and I beams. Catalogues issued by the different mills, give dimensions and principal properties of these sections besides much other valuable information, and should be in the hands of every structural draftsman.

Besides those abbreviations mentioned in connection with mechanical drawing there are several abbreviations typical of


List of Material
(For One Truss complete)
Plate 44

structural drawing. For instances, rolled shapes are designated by their form of section: 2½ x 2½ x ¾ L, etc. Pl. stands for Plate, Sp. Pl. for splice plate, Flg. Pl. for flange plates, etc.

Plate 44. Roof Truss.

Scale ¾" = 1 ft. Follow all instructions stated on plate.

(*b*) *CAMS.*

A cam is a plate or cylinder having a curved outline or a curved groove in it, which by its rotation about a fixed axis imparts a backward and forward motion to a piece in contact with it.

The motion which cams are designed to give to their followers may be *Uniform motion* or *varying motion.*

Uniform Motion.

If a body moves through equal spaces in equal intervals of time, it is said to have uniform motion; that is, its velocity is constant.

Varying Motion.

If the mechanism which moves the piece is so designed as to start and stop gradually, the shock will be avoided. The character of the motion usually employed in this case is either what is known as (a) *harmonic motion* or (b) *uniformly accelerated and retarded motion,* also called *gravity motion.*

(a) *Harmonic Motion.* If a point A travels around the circumference of a circle with uniform velocity, and another point B travels across the diameter at the same time at such a velocity that it is always at the point where a perpendicular let fall from A would meet the diameter, the point B would be said to have harmonic motion. Its velocity will increase from the starting point until it reaches the centre and from there its velocity gradually decreases to zero at the end of the path.

(b) *Gravity Motion,* or uniformly accelerated and retarded motion, is also a motion where the velocity gradually increases until it reaches a maximum at the middle of the path, and from

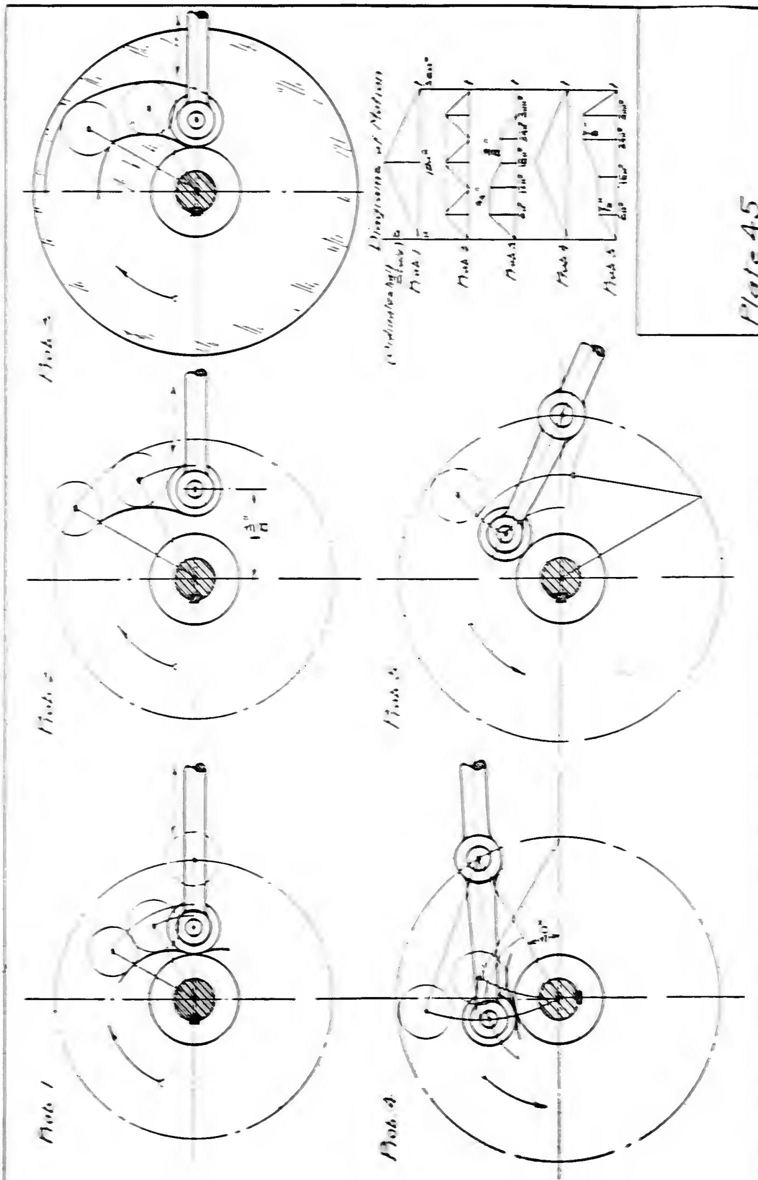


Plate 45.

there gradually decreases to the end. The rate of increase and decrease, however, is different from that in harmonic motion, the velocity being increased in gravity motion, by equal amount in equal intervals of time, the spaces traveled over in successive intervals of time being in the ratio of 1, 3, 5, 7, etc., to the middle of the path and decreasing in the same ratio to the end.

Kinds of Cams.

Cams may be divided into two general classes, *plate cams* and *cylindrical cams.* Either one of these may be designed for uni-

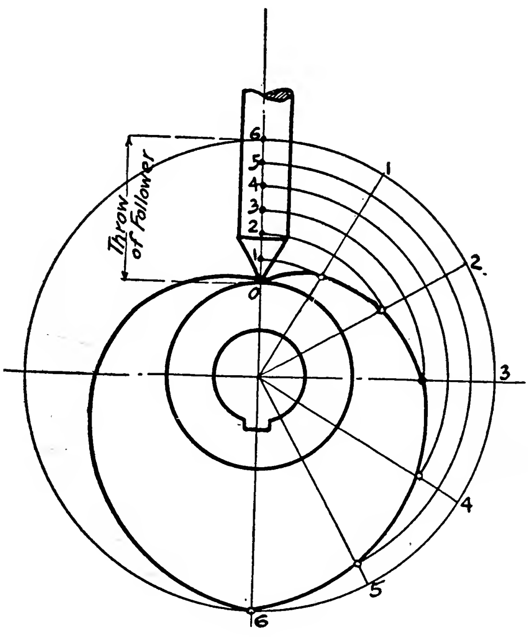


Fig. 32.

form motion, for harmonic motion, for gravity motion, or for a combination of two or even of all three.

The action of a cam will be most easily understood by the study of an example. In Fig. 32 a rotating cam is to be designed to give its follower a reciprocating motion along a straight line

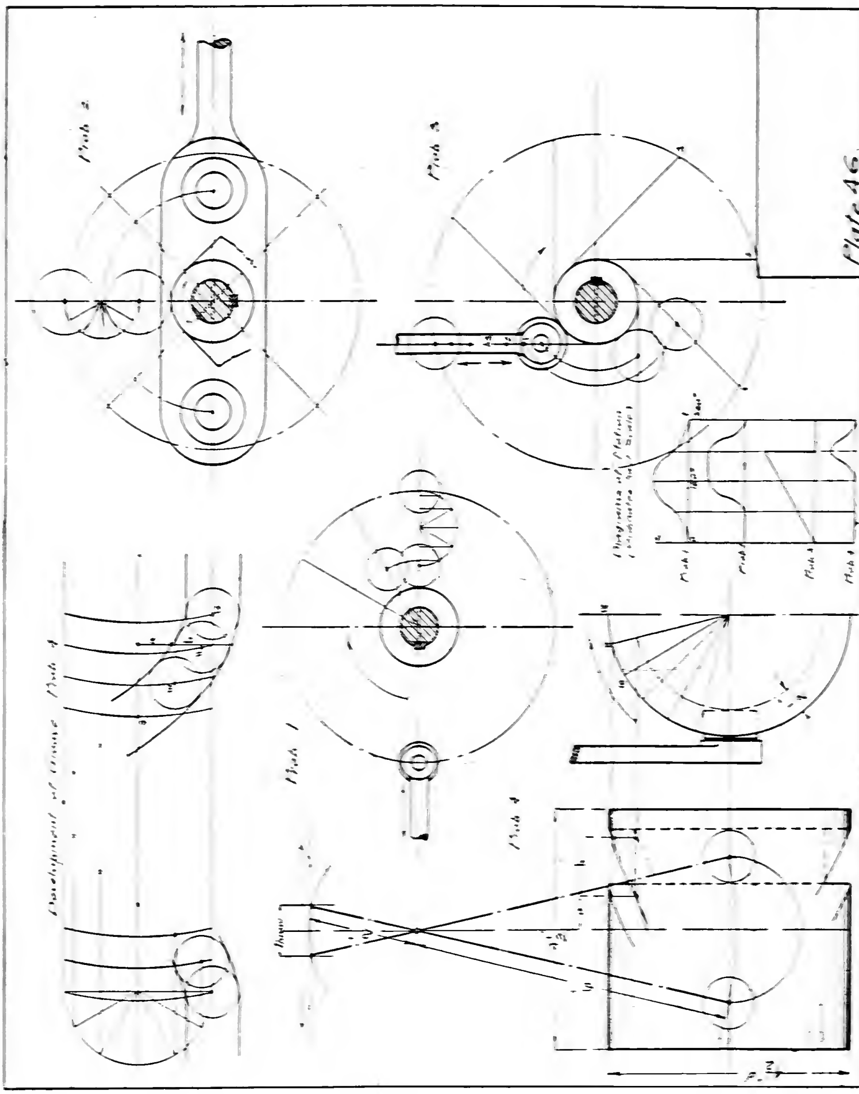


Plate 46.

passing through the cam centre, the velocity being uniform throughout both strokes if the cam rotates with uniform angular velocity.

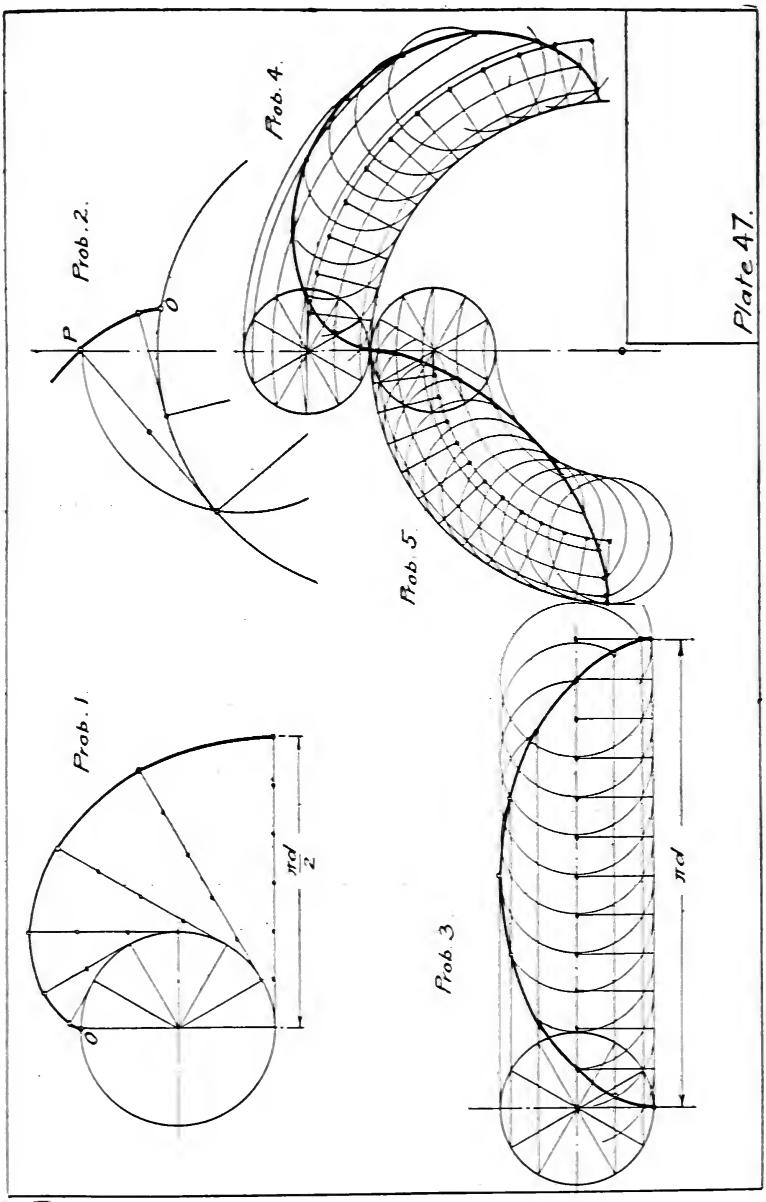
Since the cam rotates uniformly, while the follower moves with uniform velocity, the cam describes equal angles while the follower traverses equal distances. Divide the throw into any convenient number of equal parts, say six, and divide the half-revolutions of the cam into the same number of equal angles. The curve drawn through the points of intersection will be an Archimedean spiral and the same kind of curve will be found for the remaining half of the cam.

In practice the end of the follower is provided with a roller, for the sake of lessening friction, such as is used with the cams on plates 45 and 46 and the real outline of the cam itself will then not be the curve shown in Fig. 32, but a line drawn tangent to a series of circles whose centers lie on the curve shown, and whose diameters are all equal to that of the roller on the follower. (Prob. 1, Plate 45.)

A cam frequently has to actuate a point on a lever, which moves in the arc of a circle. The construction of the cam is the same as above, but the throw is now measured and divided along a circular path instead of along a straight line. (Prob. 4 and 5, Plate 45.)

In Prob. 3, Plate 46, the line of motion of the follower point does not pass through the centre of rotation of the cam. If the lengths of the tangents measured from centre of roller to point of tangency is equal to the corresponding arcs, the curve of centres would be an involute. Such curves are generally used for the cams of ore-crushing stamp mills.

The motion of the follower may be expressed graphically by means of a "Diagram of Motion," which is a Displacement Diagram on a time base, the abscissae (horizontal distances) meas-


Prob. 1
Prob. 2
Prob. 3
Prob. 4
Prob. 5
P
O
O
πd/2
πd
Plate 47.

uring time (expressed in angles to any scale) and the ordinates (vertical distances) measuring displacement of follower (any suitable scale).

Plate 45. Cams I.

Prob. 1. *Uniform Motion Cam* (straight-line motion). Throw = 1″, Roll = ¾″ dia., Hub = 1⅜″ dia.

Prob. 2. *Uniform Motion Cam.* Throw = ¾″, Roll = ¾″ dia., Hub = 1⅜″ dia. Three throws during each revolution.

Prob. 3. *Positive Action Cam* (uniform motion). Motion as per diagram. Plate dia. = 5″, Roll = ¾″ dia., Hub = 1⅜″ dia.

Prob. 4. *Uniform Motion Cam* (swinging motion). Throw (measured on arc) = 1″, Roll = ¾″ dia., Hub = 1⅜″ dia. Length of lever = 2½″.

Prob. 5. *Uniform Motion Cam* (swinging motion). Motion as per diagram. Roll = ¾″ dia., Hub = 1⅜″ dia. Length of lever = 2″.

Scale full size.

Plate 46. Cams II.

Prob. 1. *Harmonic Motion Cam.* Throw = 1⅜″, Roll = ¾″ dia., Hub = 1½″ dia.

Prob. 2. *Positive Action Cam* (harmonic motion). Throw = 1⅜″, Rolls = 1⅛″ dia., Hub = 1½″ dia.

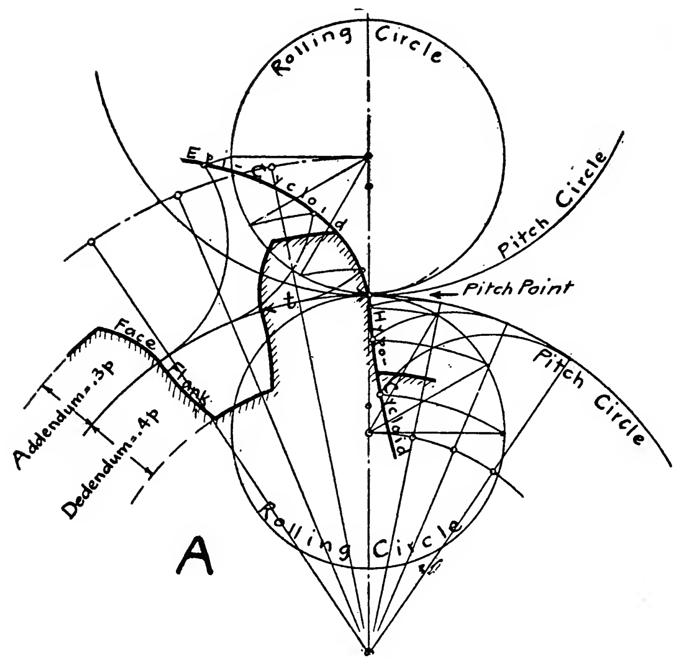
Prob. 3. *Knock-off Cam.* Throw = 2″, Roll = 1″ dia., Hub = 1½″ dia.

Prob. 4. *Cylindrical Cam.* Throw during half revolution = ⅞″, rest during second half revolution. Roll = 1″ dia.

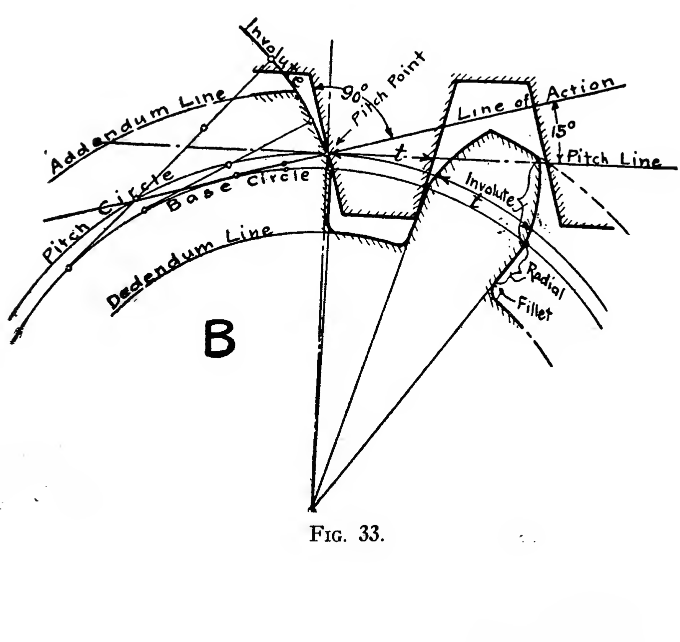
Scale 6″ = 1 ft.

C—Tooth Gearing.

When two shafts are far apart motion from one shaft to another is transmitted by belting running over suitable pulleys. When the shafts are close together, motion is transmitted by



Rolling Circle
Pitch Circle
Epi-Cycloid
Pitch Point
Hypo-Cycloid
Pitch Circle
Face
Flank
Addendum=.3p
Dedendum=.4p
Rolling Circle
A



Involute
90°
Pitch Point
Addendum Line
Line of Action
15°
Pitch Line
Pitch Circle
Base Circle
Involute
Dedendum Line
Radial
Fillet
B

Fig. 33.

tooth-gearing. Different gear may be employed, depending on the relative position of the shafts. The following three principal cases may arise:

(*a*) Shafts parallel to each other. (Spur-wheels.)

(*b*) Shafts perpendicular to each other, lying in the same plane. (Bevel wheels.)

(*c*) Shafts perpendicular to each other, lying in different planes. (Worm and wheel.)

Construction of Curves for Tooth Profile.—In order that two wheels geared together have a uniform velocity ratio, the forms of teeth must be such, that the common normal at the point of contact always passes through the pitch point, which divides the line of centres in the inverse ratio of the angular velocities. The curves, whose normals are easily found, are the Involute and Cycloid.

(*a*) Involute. By unwinding a string wrapped about a cylinder the end describes the Involute. Lay off tangents at regular intervals and make their length equal to the arc measured from the point of origin to the point of tangency.

(*b*) *Cycloid.* A point on the circumference of a circle called the *rolling circle* rolling on a straight base describes a *Cycloid.* If the rolling circle rolls upon a circle as base we have the *Epicycloid,* and if the rolling circle rolls *within* a circle as base, we have the *hypocycloid.* Should the diameter of the rolling circle = the radius of the base circle, the hypocycloid will be a straight line. In the following plate the construction of the curves is sufficiently illustrated.

Plate 47. Involute and Cycloids.

Make drawing on small size of drawing paper and work out all problems shown on printed plate. Where the involute is to pass through a given point reverse construction, that is, lay off

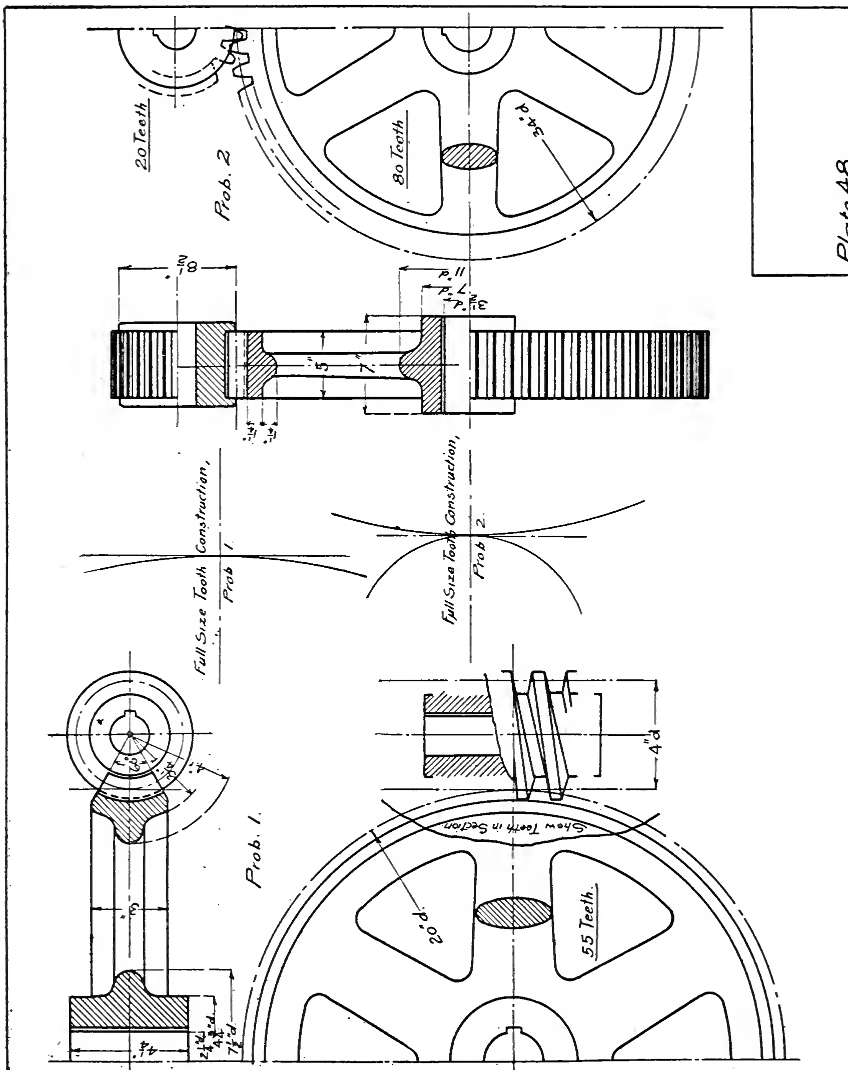


Plate 48
Prob. 2
20 Teeth
80 Teeth
34" d.
Full Size Tooth Construction, Prob 1.
Full Size Tooth Construction, Prob 2.
Prob. 1.
Show Teeth in Section
20" d.
55 Teeth.
4" d

tangent passing through the point upon the arc and find point of origin.

Construction of Tooth Profile.

A. Involute.—Two-spur wheels are assumed to be tangent to each other with their *pitch-circles* in the *pitch-point.* Through the pitch-point pass the *line of action,* which experience has found to give the best proportions when drawn at an angle of 15° to the horizontal. Tangent to this line of action draw the two *base-circles.*

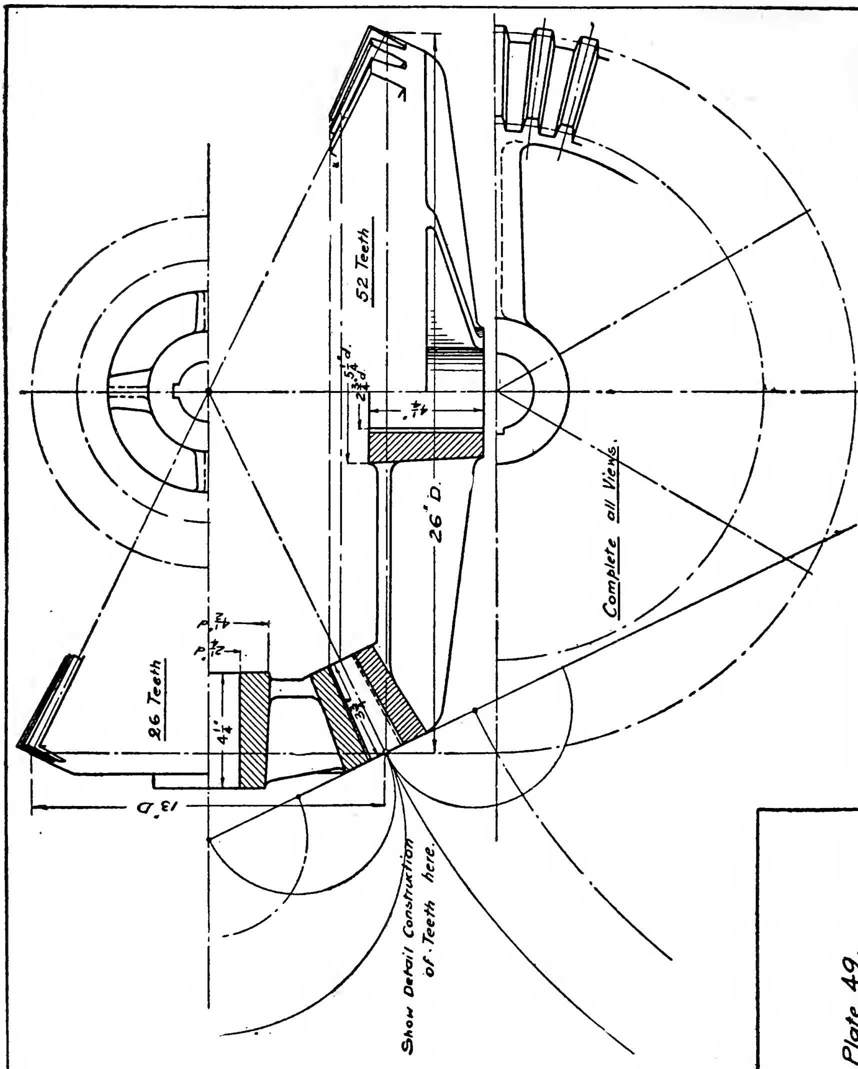
Upon these two base-circles construct the involute, arranging it so that both curves pass through the pitch-point. The points of origin therefore lie to the right and the left respectively of the pitch-point.

Draw the *addendum* and *dedendum.*

Next lay off the thickness of the tooth (half the circular pitch). The involute curve forming the addendum of the tooth extends below the pitch line to the base line. The balance of the flank of the tooth is drawn radial, joining the rim with a small fillet, whose radius is equal to the clearance.

In case of a rack or a worm meshing with an involute wheel, the face and flank of the teeth form one straight line, which is normal, that is perpendicular to the line of action, Fig. 33-B.

B. Cycloid.—(Fig. 33-A.) The curve of the face of the tooth is an epicycloid and of the flank a hypocycloid. The diameter of the rolling circle should not be greater than the radius of its pitch circle (otherwise tooth will be too weak at the root) and not smaller than half the radius. Where the diameter of the rolling circle equals the radius of the pitch circle, the hypocycloid will be a straight line passing through the centre of the pitch circle and the flank of the tooth will be radial (*"Radial flank system"*).


52 Teeth
26 Teeth
26" D.
13" D.
Complete all Views.
Show Detail Construction of Teeth here.
Plate 49.

For interchangeable wheels the same rolling circle must be taken, in any other case the same rolling circles may be taken for both wheels or their diameters may be taken in proportion to their respective pitch circles.

Proportions of Iron teeth:

Circular pitch $p = \dfrac{\pi D}{n}$, D = pitch diameter, n = number of teeth.

Diametral pitch $p^1 = \dfrac{D}{n}$

Addendum of tooth $l = .3\ p$.

Dedendum of tooth $l_1 = .4\ p$.

Thickness of tooth $t = .5\ p$ for cut teeth, $= .48\ p$ for C. I. teeth.

Plate 48. Tooth Gearing I.—Involute System.

Prob. 1. Worm and wheel, scale 6″ = 1′.

Prob. 2. Spur wheel and pinion, scale 3″ = 1′.

Show detail construction of teeth full size.

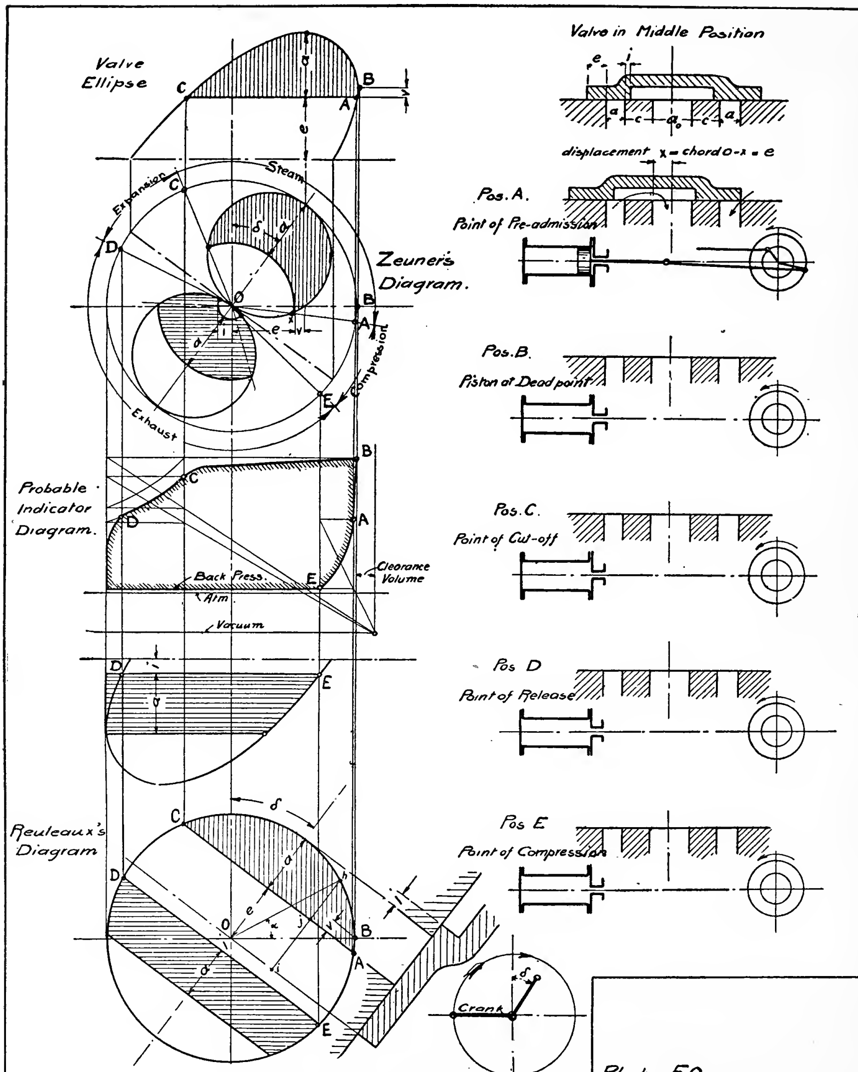
Plate 49. Tooth Gearing II.—Cycloidal System.

Bevel wheel and pinion. Scale 6″ = 1′. Show all teeth in projection in the various views. Detail construction of teeth.

(*d*) *Valve Motion Diagram.*

Valve diagrams show the relative movements of the valve and the piston and the various events occurring during one stroke. Numerous forms of diagrams are used, the most convenient one being Zeuner's diagram.

(1) Zeuner's Diagram.—In Fig. 34 the diameter of the large circle represents the displacement of the slide valve. When the valve is in position *OP*, the vertical projection *OM* represents its displacement from centre position. Make *OQ* = *OM*. If this construction is repeated, we obtain a pair of circles,


Valve Ellipse
Zeuner's Diagram.
Steam
Expansion
Exhaust
Compression
Probable Indicator Diagram.
Back Press.
Atm
Vacuum
Clearance Volume
Reuleaux's Diagram
Valve in Middle Position
displacement x = chord O-x = e
Pos. A.
Point of Pre-admission
Pos. B.
Piston at Dead point
Pos. C.
Point of Cut-off
Pos D
Point of Release
Pos E
Point of Compression
Crank
Plate 50.

which is the polar displacement diagram of the valve. For instance, if *OR* is the position of the eccentric, then the corresponding displacement from centre position is *OS*.

To find the position of the crank *L* of the engine for a given position *OP* of the eccentric, make angle $POL = 90° + \delta$.

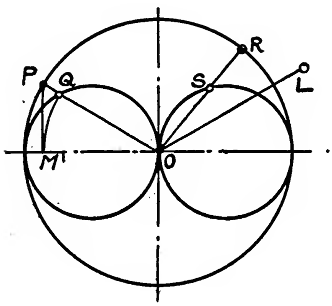


FIG. 34.

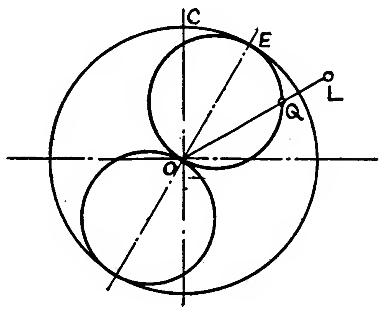


FIG. 35.

Or, if *OQ* is marked off on *OL* instead of on *OP* (Fig. 35), it will be found that the locus of *Q* is a pair of circles on the centre line *OE*, the angle *COE* being equal to the angle of advance.

Plate 50 shows the complete valve diagram. The obliquity of the connecting rod has not been taken into account.

The crank pin circle may be drawn to any convenient size. It is shown here to coincide with the displacement circle of the valve.

OA—Position of crank for beginning of admission.

OB—Position of crank for beginning of stroke.

OC—Position of crank for beginning of expansion.

OD—Position of crank for beginning of exhaust.

OE—Position of crank for beginning of compression.

Below this diagram is shown the probable form of the *indicator diagram.* The construction of the expansion and com-

pression (isothermal or hyperbolic) curves is illustrated in Fig. 36. In actual practice the steam line usually slopes down-

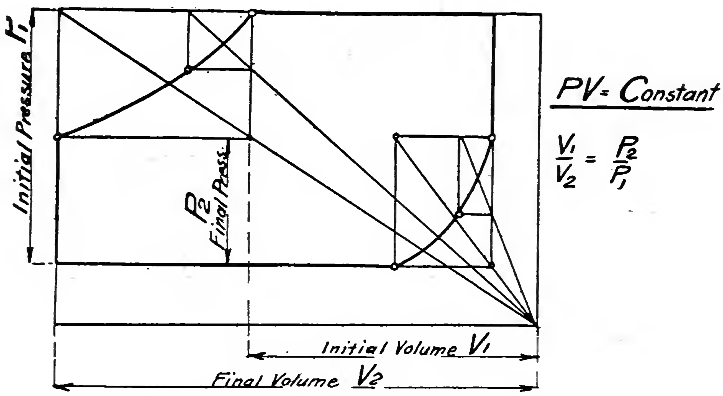


FIG. 36.

wards a little because of the falling pressure due to the decreasing port opening.

(2) **The Valve Ellipse** is a great assistance in understanding Zeuner's valve diagram, and it also shows the speed with which the valve moves at different parts of its stroke, when opening or closing the ports.

The diameter of the crank circle may be divided into 10 equal parts and the chords of the valve circle (polar diagram) laid off as ordinates for the valve ellipse (linear diagram on displacement base.) For instance, at the dead point the port is open to the extent of v.

Reuleaux's Diagram.—The diagram constructed by Professor Reuleaux is also very convenient for the solution of simple valve problems.

Mark off on a line making an angle δ with the vertical, the outside lap e, inside lap i, and steam port a.

Starting from the dead-point when the crank has moved an

angle α to the position *oh,* the valve has moved a distance *hi* from its central position. The port-opening is *hj.*

The lead is found by drawing a perpendicular from *B* upon *AC,* as this is the port-opening when $\alpha = O$.

The maximum port-opening is *a.*

Cut-off takes place at *C.* Steam admitted at *A.*

Plate 50. Valve Motion Diagram.

Make a valve motion lay-out by means of Zeuner's and Reuleaux's Valve diagram for a single slide valve steam engine. Also construct the valve ellipse. The dimensions of slide valve and ports are to be taken from the marine engine plate. Angle of advance = 35°. Scale of diagram three times full size.

Draw up probable indicator diagram for 65 lbs. abs. pressure and 17.5 lbs. back pressure. Scale of pressures 1″ = 20 lbs. Assume 10 per cent. clearance volume.

Show the valve and piston in the positions *A, B, C, D, E.*

Also show the valve in centre position, fully dimensioned.

In these positions the valve is to be shown full size, while the engine mechanism may be shown to any convenient scale.

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